University of Cape Town
Department of Physics

The role of tutors in the effectiveness of cooperative learning physics tutorials

Reuben Double Koontse

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Abstract

Group problem solving tutorials have been in use in the Department of Physics at the University of Cape Town for more than a decade. They are implemented with the belief that students have the opportunity to develop problem-solving skills through interacting with each other, and are able to make sense of physics concepts through conversation and reasoning with their peers. These problem solving sessions are supervised by tutors who are typically postgraduate students. The present project focused on understanding the role that these tutors play in facilitating learning in cooperative problem solving physics tutorials, and explored the factors that result in a group of students deciding to call a tutor, the different ways in which tutors interact with a group of students, and the factors which are related to the intervention of tutors that affect the learning outcomes in a physics cooperative learning session. Data were obtained from three sources: written surveys, interviews of tutors and mainly from videotaped observations of student - tutor interactions in group problem solving sessions. A worksheet-based analysis protocol was designed to facilitate the analysis of video segments involving the intervention of tutors. The results include a hierarchical level scheme that characterizes where the learning awareness of the students working in the group is focused. Whether or not the tutor is able to discern the level at which the group is operating was found to be the most critical factor affecting the quality of the tutor-group interaction and hence the progression in the students' understanding. A number of tutoring styles were identified which also affect the both the dynamics and learning possibilities in the group. The observations of tutors in action were contrasted with the learning expectations expressed by instructors, tutors and students in written questionnaires and interviews. The implications for tutor training and the design of physics cooperative learning activities is discussed.

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Life has no meaning, but its main goal is happiness
within oneself and success in the eyes of others...

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Introduction

Cooperative learning has grown in popularity among physics educators worldwide (Heller *et al.*, 1992) in the light of increasing research-based evidence that it contributes towards effective learning of physics. A typical physics group problem-solving tutorial will involve students working in groups of usually three or more on a set of questions given by the instructor. These sessions usually rely heavily on tutors to facilitate the session and to assist students as they work.

1.1 Problem solving in physics

Solving problems is the heart of the work of the physicist (Fuller, 1982). It is a process that involves following appropriate reasoning paths to obtain knowledge about physical objects or processes. It can be of either a qualitative or quantitative nature and may often be carried out as a modelling activity. A modelling strategy allows the application of scientific and mathematical knowledge to physical objects and processes (Hestenes, 1987), in order to provide a consistent conceptual representation of a phenomenon. Models result from the cognitive process of applying the design principles of a theory (Hestenes, 1992), and have different forms, mathematical or otherwise.

Problem solving as a component of physics instruction is performed to enhance conceptual understanding of students. Reconciling everyday experience and intuitions with each other and with physics principles, which results from concept development, is thus, an essential aspect in problem solving. In order to develop conceptual understanding, Van Heuvelen, 1991, says that construction of a knowledge structure is a necessary condition. This knowledge construction may be achieved when there is transfer of conceptual understanding from one context to another.

Subsequent to a proper grasp of physics concepts, problem solving becomes an even more meaningful activity. More complex problems could be approached with a robust understanding of the concepts. Attaining competence in problem solving in physics is supposed to lead to development of critical thinking. It is supposed to develop intuition for the physical world. Ability to solve more complex problems experienced in the real world is the ultimate goal.

1.1.1 Students' approaches to problem solving

First year physics courses require problem solving which relies on conceptual as well as analytical reasoning, effective organization of knowledge and abstract representation of physical phenomena (Sharma *et al.*, 1999). Students are asked to perform problem-solving activities with the belief that it will result in them learning the physics. However, the way in which students approach solving physics problems is often very different from the way in which experienced physicists approach the activity (Van Heuvelen, 1991). Students' ideas about the nature of physics, as well as what it means to learn and be successful in physics affects the way in which they approach their own learning of physics. Students often view physics problems as isolated situations that require equations and formulae to determine some unknown quantity (Reif, 1995).

Many students regard diagrams and qualitative reasoning as being subsidiary to learning physics. Backward means-end analysis, which mostly focuses on the manipulation of isolated equations from the beginning of the problem-solving process, is common with students (Van Heuvelen, 1991; Elby, 2001; Redish, 2003). Students hasten to find a formula, identify the knowns and the unknowns and then substitute in the numbers to get a solution. This is done with very little engagement that allows one to be able to develop any problem solving skills or reason qualitatively about the physics involved. This approach results from a limited use of conceptual knowledge when solving problems and is driven by an emphasis on obtaining an answer (Buffler & Allie, 1993). Maloney, 1994, states that means-ends analysis is a general heuristic process of identifying the goal, and then carrying out available operations to reduce the difference between the current state and the goal state. Many students in introductory courses consider problem solving to be independent of physics concepts and principles being taught. In responding to an interview by Heller *et al.*, 1992, one student said, "I understand the material but I just can't solve the problems", showing that to him problem solving is a separate aspect to understanding physics.

Extracts from student interview dialogues, Linder, 1992 have been used to illustrate that what students perceive as practically useful in physics classes may be providing support for: students to rote-learn physics; the association of conceptual understanding with an ability to solve the stereotypical tutorial problems; and the discouragement of coherent understanding. Simply demonstrating rote knowledge does however, not imply deep understanding or learning. Without learning with understanding, transfer to new situations or contexts rarely occur (Bybee, 2002). The ability to solve numerical problems has been dismissed as a reliable indicator of conceptual understanding (McDermott, 1991).

1.1.2 Research-based methods for teaching problem solving

A dominant theoretical framework on problem solving has been the information-processing framework (Fuller, 1982; Maloney, 1994). It focuses on how an information processor takes a natural language problem statement, translates it into an internal representation on which it can operate, carries out the appropriate operations, and then outputs the results. A particular method following the information-processing framework will specify how to analyse a problem initially and how to make well-judged decisions in order to construct its solution. The general sequence involves initial problem analysis, construction of a solution and finally checking or verifying if the solution is satisfactory. The types of problem can be categorised broadly as qualitative or quantitative.

Qualitative problems are those that involve non-formal methods that rely on descriptions in the form of words or pictures (Reif, 1995) and may be more effective to develop conceptual understanding than quantitative problems (Hewitt, 1998). Mullin, 1989, suggests that explaining the ideas of physics without mathematics is a powerful way to learn. Physicists depend on qualitative analysis and representation to understand and help construct a mathematical representation of a physical process (Van Heuvelen, 1991).

Quantitative problems involve using formal modes of description, with precisely defined symbols and explicit rules for their manipulation (Reif, 1995). They involve identification and use of heuristics and could be solved by use of mathematics alone. The objective in this type of problems is usually to find the numerical value of an unknown quantity.

The multi-representational problem-solving strategy is one of the newer methods that require the use of pictorial, diagrammatic, procedural, and mathematical physics skills (Reif, 1995; Van Heuvelen, 1991). A pictorial representation portrays the situation, step by step from the start to the end of a process. This helps in the construction of diagrams that are more physical depictions of the process. The diagram serves several purposes. It summarises the prominent features of a process and multiple diagrams can be used to describe more complex processes. Diagrams assist with construction of the mathematical representation of the situation (Van Heuvelen, 1991). The practice of constructing and interpreting diagrams of various kinds is claimed to contribute to the development of physical intuition (Hestenes, 1987). In using a multi representational strategy, the solution to a problem relies on a whole series of representations with the value of the unknown being only a small and final part of the solution.

1.2 Cooperative learning problem solving tutorials

Physics education research has and is continuing to provide alternatives that can be used for a better and more effective learning of physics. It has brought about innovative methods in the teaching and learning of physics at university level, which comprises lectures, laboratories and tutorials. Some of these include interactive lecture demonstrations (ILDS) (Sokolof & Thornton, 1997), peer instruction / conceptests (Crouch & Mazur, 2001), just-in-time teaching (JiTT) (Novak *et al.*, 1999), Tutorials in Introductory Physics (McDermott & Shaffer, 2002), Activity-Based Physics (ABP) (Steinberg & Sabella, 1997) and cooperative problem solving tutorials (Heller et al., 1992). Most of these are based at least in part, on the outcomes of physics education research that seek to replace passive learning with active experiences (Laws, 1997). Amongst them, the use of cooperative-learning tutorials has grown in popularity, as more educators believe it results in better learning of physics through problem solving.

Cooperative learning is based on theory and research and has a direct application to instruction (Smith *et al.*, 1991). It came about as it became evident that the traditional transmissionist mode of instruction was insufficient. Much work has been done to show that a student's approach to physics and their naïve problem solving strategies do not change by the end of their first year of traditional instruction. Force Concept Inventory scores (Hestenes *et al.*, 1992) and other evidence suggest that, when material is covered at the traditional pace, few students achieve a deep understanding of such topics as Newtonian mechanics (Elby, 2001).

1.2.1 Reasons for using group work in physics teaching

Cooperative-group tutorials give students opportunities to practice problem solving strategies until they become more natural (Heller *et al.*, 1992), and it is based on the premise that groups can solve more difficult problems than individuals, and that each individual can then subsequently practice the planning and monitoring they need to become good problem solvers. In these sessions students can get practice developing and using the language of physics. Through this they can deal with and resolve their misconceptions (Heller *et al.*, 1992).

Cooperative grouping provides a supportive environment for students to practise problem solving with access to help from experts in the form of tutors. It provides the context within which students' learning can be encouraged and optimised. The emphasis in the tutorial is not just solving the standard quantitative problems found in traditional textbooks but also on the development of important concepts and scientific reasoning skills (Van Heuvelen, 2001). It is believed that group work is an effective activity that helps students learn complex skills. Redish, 2003, says that for most individuals learning is most effectively carried out through social interactions. The social interaction, says White *et al.*, 1995, is with physics as the context, and helps in the transition from high school to university physics studies. Cooperative learning practices a "none of us is as smart as all of us" theory (Johnson *et al.*, 1992). Learning is not an isolated activity but rather a social activity influenced by among others local context and task formation.

The benefits offered by cooperative learning however cannot be achieved by simply putting students together into groups. Cooperation is not having students sit side by side at the same table to talk with each other as they do their individual assignments (Smith *et al.*, 1991). Neither is it assigning work to a group of students where one student does all the work and the others put their names on the final product. It is not having students do a task individually with instructions that the ones who finish first are to help the slower ones (Smith *et al.*, 1991). Buffler and Allie, 1995, say that naive application of cooperative activities could produce adverse outcomes. Extensive group work for example might actually hinder the learning of the best students who spend their time dealing with other students rather than extending their own knowledge and skills.

Proper structured cooperative learning is said to raise the achievement of all the students in the group (Johnson *et al.*, 1994). An overview of work on cooperative learning group indicates that students involved in cooperative learning schemes consistently outperform those in the more traditional teacher oriented systems (Heller *et al.*, 1992; Hake, 1998). It builds positive interdependence among students. Students develop a positive attitude toward their own learning. In soliciting feedback from students who underwent a cooperative learning program at the Ohio State University, Andre, 1999, got responses like; " I really enjoyed the groups this time for physics"; "I like the focus on team work"; " ... I think team work in engineering may be the best decision ever made in college", to " I think cooperative learning is one of the most important aspects of the Gateway Program and one of the best reasons to participate in the Gateway Program".

Prosser and Millar, 1989, say that students' attitudes to learning are crucial to their understanding of physics. Cooperative learning promotes higher-level reasoning, critical thinking and metacognitive skills necessary for meaningful problem solving. It is thus valid to say more effective learning is achieved. To achieve the benefits offered by cooperative learning, several considerations have to be made when implementing it.

1.2.2 Factors affecting cooperative learning

Current student life in secondary schools is dominated by competitive and individualistic activities that ignore the importance of positive interdependence (Johnson *et al.*, 1992). Introductory university courses that attempt to get students to work collaboratively or that try other techniques to engage in learning are often viewed by students as gimmicks, and thus simply to be tolerated rather than invested in (Bybee, 2002). Students' reluctance to participate productively in group problem solving thus cannot be overlooked or underestimated. The following are some factors that should to be considered when implementing cooperative learning.

(a) Organisational factors

Group size, assignment of roles, tutor-student ratio and the mechanism by which groups are constituted are some of the most frequently mentioned organisational factors that influence learning outcomes in group problem solving tutorials (Johnson *et al.*, 1994).

Three or four students per group is the optimal size according to Heller *et al.* 1994. Johnson *et al.* 1992, say that a greater individual accountability is obtained with a smaller sized group. The gender and performance composition of the group should be balanced. Another factor to be considered is that of equitable participation from all group members. The problem of dominance or passiveness by one student can be addressed by the assignment of roles to group members. The roles can be organised such that one group member becomes a recorder, another manager and the third being a skeptic. The length of time that group members should stay together is another factor that has to be considered.

In designing cooperative learning workshop tutorials at the University of Sydney, formal assessment procedures were deliberately left out (Sharma *et al.*, 1999). This technique allowed students to openly discuss and work on problems, and to explore different avenues of solutions, without feeling that there was a one correct solution to be marked. It also meant that the atmosphere was stress free, conducive to independent learning, and student driven rather than assessment driven. The control and responsibility for learning was with the students. On responding to the evaluation of the workshop tutorials at the end of the course, one student commented, "Assessing the tutorials would be disastrous. It would put extra unnecessary pressure on the students. The tutorials encourage learning the concepts because we want to, not because we have to".

(b) Facilitators

Another important factor that is influential in the running of physics group problem solving tutorials is the role that facilitators play. The tutorials involve students working cooperatively on tasks with assistance from a number of roving tutors (Allie & Buffler, 1998). These tutors are typically postgraduate students. They act as both facilitators and consultants (Smith *et al.*, 1991). The tutors are supposed to help students see the physics behind the questions and also help them with procedures in problem solving. They are there to see to it that problem solving becomes a meaningful activity for students. Another role for the tutors is that they should make sure that students are working cooperatively so as to enjoy the benefits offered by cooperative learning. Many students see the tutor as having all the answers and may have a tendency of depending on the tutor to do the work for them or give them solutions. Many tutors likewise will be tempted to give students direct answers to their questions lest they are perceived by students as incompetent. As much as the students are the focus of the whole activity, the tutors are the pivot around which the whole activity revolves. Students view the tutors as experts.

In their Conceptual Understanding Program (CUP) at Monash University , Australia, Mills *et al.*, 1999, say that an awareness of the following key principles for student learning is vital: in the learning process each student constructs his/her understanding; an atmosphere of trust promotes good learning; for active learning to take place, the person in charge facilitates discussion rather than provides 'correct answers'; concepts are most readily understood if studied in real life context. An understanding of these principles by tutors would therefore make their practice more effective.

(c) Task design

Setting appropriate tasks is a crucial skill for the instructor preparing a group problem-solving tutorial. The choice of questions such as context-rich problems that promote conversation is important. The nature of the problems is that they should be designed such that there is something to discuss initially (Heller *et al.*, 1992). This helps in getting the attention of the entire group to focus on the tasks at hand. It also helps establish rapport. The problem must be complex enough so that none of the students can solve it immediately. Students should not be able to solve it in a few steps by plugging numbers into formulae. They must however be simple enough that the solution once arrived at can be understood and appreciated (Heller *et al.*, 1992).

The design of the problem is crucial to the development of problem-solving expertise of the student (Van Heuvelen, 1991). The crucial factor in a task is to have some ground for interpreting problem solving and reasoning that use intuitive knowledge. Together with the above components an awareness of the variation in the understanding of a phenomenon to be learned is invaluable in preparing instructional material including task design in cooperative physics problem solving tutorials.

1.3 Learning problem solving through variation

The behaviourist, cognitivist and constructivist modes are some of the various paradigms that describe approaches to learning. Marton and Booth, 1997, made a phenomenographic claim that learning is only possible through variation. This presupposes that an approach to learning is therefore understandably and empirically related to the complexity of way of experiencing a phenomenon. Studies by Linder and Erickson, 1989, and Pong, 2000, suggest that because learning is about developing a more complex structure of awareness then variation is a necessary condition.

Phenomenography is an analytic and descriptive research model that characterises the experience of a phenomenon such as learning into categories of description. It states that a phenomenon can be experienced in a limited number of qualitatively different ways. Here experience is characterised as the internal relationship that is constituted between individuals and phenomena. Instead of studying learning per se, a phenomenographer would study the experience of learning and the outcome of such a study would be qualitative descriptions of the variation found in the experience of learning (Marton *et al.*, 1993). It was initially concerned with student learning and included descriptions of the variation in ways of experiencing the processes of higher education (Marton *et al.*, 1997). Recently the focus is on the qualitative variation in the way the student's object of study is understood (Prosser & Trigwell, 1999). Studies on relationships between way of experiencing a phenomenon and approach to learning about a phenomenon have been done qualitatively and quantitatively at both task and topic level (Prosser *et al.*, 1996; Prosser & Millar, 1989).

While a well designed task is vital for the promotion of active learning and the construction of one's internalised meaning, "variation" is another essential aspect in learning. The variation refers to characterising a way of experiencing a phenomenon such as a problem solving learning task in terms of its critical aspects as discerned by the learners. Bowden and Marton, 1998, claim that, "Without variation there is no discernment. Learning in terms of changes or widening our ways of seeing the world can be seen in terms of discernment, simultaneity and variation". For learning to occur there needs to be discernment of variation. A task design focusing on variation in ways students experience learning through problem solving in a physics tutorial must include a range of individual's experiences. The construction of the whole problem should aim at maximising the possible variation. In group problem solving tutorials, different students bring about different views in discussing problems. This results in the variation in terms of how other group members view the problem, their scope is widened and hence learning is achieved.

1.4 The present study

Cooperative problem solving physics tutorials are often based on the assumption that both students and tutors understand what the instructor intends to happen, and that the tutors know their role and contribute meaningfully to the session. However, the role that facilitators play in effective running of group problem solving tutorials has not been well studied.

McDermott, 2001, says that tutorials require ongoing preparation in both the subject matter and instructional method of tutorial instructors. In view of the scarce information about the central role of tutors in physics group problem solving tutorials, this study intended to look at the following:

~ What are the factors that result in a group of students working in a physics cooperative learning tutorial deciding to call a tutor?
~ What are the different ways in which tutors interact with groups of students?
~ What are the factors that affect the learning outcomes in a physics cooperative learning tutorial, which are related to the intervention of tutors?

The study obtained data from three sources: written surveys, interviews of tutors and videotaped observations of student-tutor interactions in group problem solving tutorials. The surveys and interviews served as a basis for understanding what students and tutors perceived to be the purpose of group problem solving tutorials. The video observations, which constitute the core data of the study, captured the actual interactions between students working on problems in groups, and in interacting with tutors. The video data was then analysed by looking at the variation in the focus of students when working on tutorial tasks. The array of approaches used by tutors in assisting students was also looked at. By integrating results of the analyses with other work on group problem solving tutorials (Heller *et al.*, 1992; Linder *et al.*, 1997), implications for effective tutoring were inferred.

2

Tutors' and students' expectations of physics tutorials

2.1 Written surveys

In order to understand how the students themselves view the purposes of small group physics tutorials, a written survey instrument was designed based on the Maryland Physics Expectation Survey (Redish *et al.*, 1998), Appendix A. These items explored whether students view physics knowledge as a collection of pieces or as a more integrated whole (coherence); whether they view physics as consisting more of formulae and facts or as a set of ideas (concepts); the extent to which they view physics as connected to their lives outside the classroom (reality link); and the extent to which certain varieties of sustained effort lead to success in physics class (Elby, 2001). The full survey (25 items) was administered to 203 first year engineering physics students and 122 first year (science) physics students after their first semester at university. The students had participated in weekly small group tutorials during this time. Seven physics tutors and nine physics academics at UCT also completed the same survey, although the tutors and lecturers were given statements, which probed what they thought the students' views were. For example, in the survey given to tutors and lecturers, an item like statement number 19 (see Table 2.1) read, "students think that physics has little relation to what they experience in the everyday world".

The following instructions were given on the survey:

Here are 25 statements, which may or may not describe your beliefs about first year physics at UCT. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean: 1: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree.

Answer the questions by circling the number that best expresses your feeling. Work quickly. Don't over elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you don't understand a statement leave it blank. If you understand, but have no strong opinion, then circle 3.

The questions in the survey were designed around three broad categories: ideas about physics as a discipline, ideas about learning physics and ideas about small group problem solving tutorials. The tutors' questionnaire had an additional section, which allowed them to express what they think about the purposes of small group physics tutorials, together with their role as tutors in these tutorials.

2.2 Results of the surveys

The 25 items in the survey were sorted into three broad categories and are presented in Tables 2.1, 2.2 and 2.3. The average of the numerical responses from students (S), tutors (T) and lecturers (L) are also presented.

Table 2.1 *Survey items relating to physics as a discipline.*

No	Statement	Average S	Average T	Average L
1	One of the main skills for students to get out of Physics I is to learn how to solve physics problems.	4.1	4.1	4.3
12	The physics lecturers should think about their own experiences as students and relate them to the topic being taught in lectures.	3.9	3.6	3.4
17	An important skill for students to get out of Physics I is to learn how to reason logically about the everyday world.	4.2	4.4	4.6
19	I think that physics has little relation to what I experience in the everyday world.	2.2	3.9	3.4
24	Physics should help me better understand situations in everyday life.	4.0	4.4	4.2
25	It is possible to pass Physics I without understanding physics very well.	2.0	4.0	4.0

All three groups agreed that physics should help students better understand situations in everyday life (item 24). However students differed with tutors and lecturers on the statement that said physics has some relation to what they experience in the everyday world (item 19). Although all agreed that one of the main skills for students to get out of Physics I is to learn how to solve physics problems (item 1), students generally disagreed with the statement that, it is possible to pass Physics I without understanding physics very well (item 25).

Table 2.2 *Survey items relating to learning physics.*

No	Statement	Average S	T	L
2	When learning physics, I find it helpful to make explicit connections to the everyday world.	3.9	4.1	4.8
3	I think that "problem solving" in physics basically means matching problems with equations and then substituting values to get a number.	2.4	3.9	4.1
5	I spend a significant amount of study time trying to understand the derivations or proofs given in class.	2.8	4.0	3.8
6	I think that it is important for the lecturer to explicitly develop problem solving strategies in lectures.	4.3	4.0	4.1
7	I use my physics textbook regularly.	3.6	3.6	2.7
8	When an exam or test is marked, most marks should be allocated to the final answer only.	1.6	1.3	1.7
9	I find that the best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail.	3.7	3.0	3.1
14	I think that spending a lot of time (half an hour or more) working on a single physics problem is a waste of time.	2.9	2.9	1.7
15	I think that I do not have to understand the concepts behind the equations used to solve a particular problem.	1.8	3.5	3.2
16	When first year physics exam problems are marked, a significant emphasis should be placed on the problem solving method used.	3.9	3.4	3.8
21	The most crucial thing in solving a physics problem is finding the right equation to use.	3.3	1.7	2.4
22	I think that if I have all the required equations on my formulae sheet, then I will do very well in the exam.	2.6	3.0	3.4

All agreed that it is helpful to make connections to the everyday world when learning physics (item 2). Lecturers had a stronger opinion on the issue. Everyone generally agreed that lecturers should explicitly develop problem-solving skills in lectures (item 6). Tutors and lecturers thought that students believed that they did not have to understand the concepts behind the equation used to solve a particular problem (item 15). Students generally disagreed with the statement. They also confirmed this by saying a formulae sheet is not all that they required to pass exams (item 22).

Table 2.3 *Survey items relating to group problem solving tutorials.*

No	Statement	Average		
		S	T	L
4	I think that working with other students in small group problem solving tutorials is an effective way for students to learn physics.	4.0	4.0	4.0
10	I think that it is necessary for the lecturer to meet regularly with the tutors in his or her class in order to prepare them for tutorials.	4.3	4.6	3.2
11	The main role of the tutor in a tutorial is to assist the students with conceptual understanding, rather than providing us with the right answers to the problems.	4.4	4.7	4.6
13	In order for small group tutorials to be effective, the tutors need to be appropriately trained.	4.5	4.6	4.1
18	The lecturer should attend the afternoon tutorials for his or her class for at least part of the time.	4.2	4.1	3.3
20	I think that physics tutorials are very useful.	4.0	2.3	2.9
23	When I solve a physics problem, I explicitly think about the concepts that underlie the problem.	3.8	4.9	4.4

Students claimed that small group problem solving tutorials are an effective way for them to learn physics (item 4). Lecturers and tutors views supported the students' claims. However there was a difference of opinion regarding the statement that tutorials are very useful (item 20). Students agreed while tutors disagreed by saying that they do not think that students see the usefulness of tutorials. Lecturers did not have any strong opinion on students' views about this issue. Students and tutors felt that it was necessary for the lecturer to meet regularly with tutors of his or her course to prepare them for tutorials (item 10), while the lecturers did not necessarily agree. However, all did agree that in order for small group problem solving tutorials to be effective, tutors need to be appropriately trained (item 13). The lecturers belief that students thought that the main role of a tutor was to assist students with conceptual understanding rather than providing students with the right answers to specific problems was in agreement what students said (item 11).

2.3 Interviews with tutors

After completing the survey all the tutors were interviewed concerning their views about tutorials. They were all MSc and PhD students with tutoring experience ranging from one to ten years. The interviews were transcribed and analyzed in the following categories: purposes of tutorials, the role of the tutor, the advantages of cooperative learning, and problems encountered in tutoring. Summaries of the main issues raised in the interviews are presented below.

2.3.1 Purpose of tutorials

Some tutors claimed that the purpose of tutorials was to develop conceptual understanding while others said that it was to develop problem-solving skills, or to provide students with the opportunity to practice them for what they will meet in tests and examination. All the tutors questioned whether the students themselves really understood the purpose of the tutorials. This, they claimed, was supported by the fact that students sometimes struggled to complete one question to its final numerical solution, at the expense of understanding principles and approaches involved in all the questions, as illustrated by:

> *Students do not necessarily understand the purpose of the tutorials; otherwise they will not stick to number one until they finish it.*

One tutor suggested that if the tutorial was to be effective, then the questions should be linked to each other:

> *Questions shouldn't be independent, they are but they shouldn't.*

2.3.2 Role of the tutor

Tutors saw their role as being available to help the students understand the physics behind the problems, and they emphasized that assisting students with conceptual understanding was one of their major duties. Many stated that they really should know what they are going to talk about before they help the students, as illustrated by:

> *There is nothing worse for students to have a tutor coming to them and explaining the incorrect thing. Students see tutors as experts.*

2.3.3 Effectiveness of cooperative learning

Most tutors agreed that group work would be more effective if better structured. They highlighted that the students themselves appeared to be unaware of the purpose of cooperative group work. For example, one student from a group often calls a tutor while others continue to work on the problem. Some tutors suggested that groups should not be heterogeneously constituted, as was the case, and suggested that students with similar academic ability should be made to sit together. One tutor said:

> *The better students will actually gain more because they are the ones doing the problem solving. Struggling students just sit and watch. It's important for the tutor to know if there are students in a group who are struggling.*

2.3.4 Problems encountered

Tutors were concerned that students think the purpose of tutorials is just to get solutions for the problems. They were also concerned about the apparent lack of motivation from students, for example:

> *Students should be self motivated, but what I'm noticing over the last two years is that students have been less and less motivated, on the tutoring side it's more and more... they sit there with a blank face, you can see that the brain has not switched on. They are simply waiting for you to write the answer and that's all they want.*

All tutors emphasized the fact that if tutors are not aware of the approach used by the lecturer in class and what he / she wants to be emphasized in tutorials then productive tutoring will always be difficult to achieve:

> *You can't expect the tutor to explain all the work from scratch, it's frustrating for the tutor and it puts the tutor in a bad mood.*

> *Another problem is that sometimes the tutors themselves do not understand the work. The lecturer should know how much the tutor knows.*

2.4 Summary of views about tutorials

The analysis of the written surveys suggests that there are slight differences between what lecturers and tutors thought about the way that students generally view physics as a discipline. The lecturers' and tutors' belief that students thought that problem solving tutorials have the potential of being an effective mode of learning physics was in agreement with the students' view. The interviews with the tutors validated their survey responses as well as providing them with an opportunity to reflect upon their own practice. Many tutors admitted not to have seriously thought about issues such as the purpose of tutorials and their role as tutors in cooperative learning sessions. In addition, some tutors admitted to not knowing how to effectively help students in tutorials.

The expectations and beliefs about what it means to learn physics have direct implications on how students conduct themselves in group problem solving tutorials. How the tutors interact with students is also guided by their preconception about their role in group problem solving sessions. The chapter that follows characterises the variation in the students' focus of awareness when approaching problem tasks.

3

The focus of students working in a tutorial

The Department of Physics at the University of Cape Town has a large tutorial room in which a class of as many as 150 students can work. For a class of this size, the tutorial sessions are facilitated by an average of six tutors. These tutors move about the whole room, approaching a group when they are called or just to check how the group is progressing. Figure 3.1 shows a photograph of the room with students working during a typical tutorial.

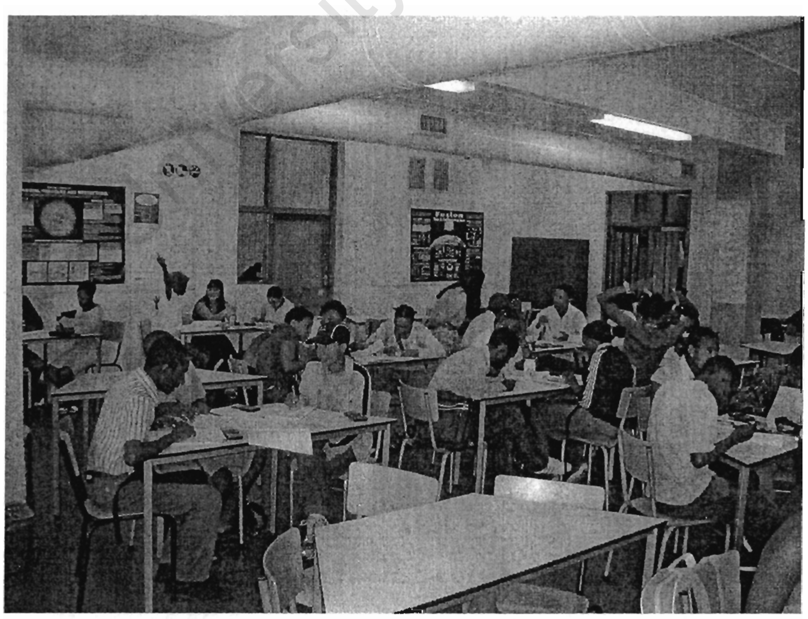


Figure 3.1 *Photograph of a tutorial in progress in the large open plan room in the Physics Department..*

3.1 Video observations

The main body of data for the present study were obtained from videotaped observations of students working cooperatively in groups of three on tutorial tasks. The tutorial room has a specially constructed observation room, which is equipped to facilitate video taping of one group of students working in the large venue (see Figure 3.2). A camera in the observation room may be focused on the students through a unidirectional window and is invisible to the students sitting in the tutorial room. Both the students and the tutors are consulted and asked whether or not they mind being video taped during the session. The conversation between the students themselves and between the students and a tutor is captured through a microphone "Realistic PZM" available from Radio Shack, U.S.A., which is situated on at the centre of the table of the group that is being observed. The microphone is linked to the video recorder, via an amplifier. There is also a television in the observation room, which is used to monitor the recording session.

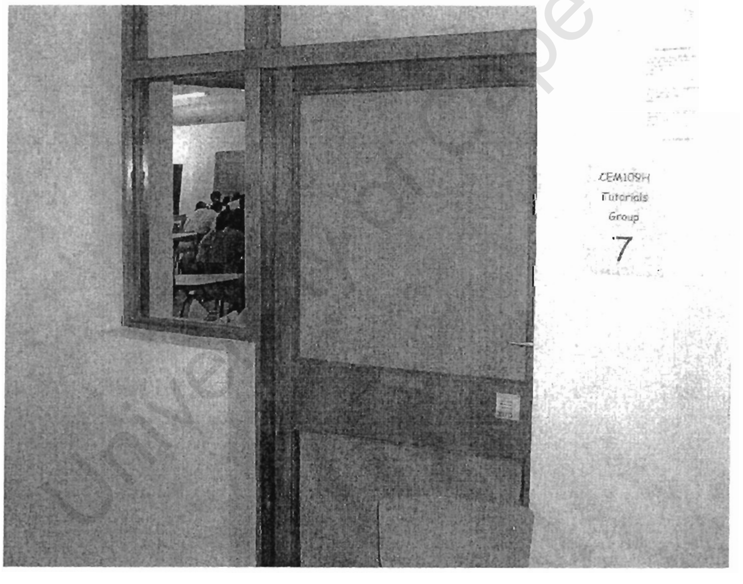


Figure 3.2 *Photograph of the observation room which extends off from the large open plan tutorial room.*

The students observed were from a variety of first year physics classes at the University of Cape Town, including physics majors (PHY122S), students on the General Entry Programme to Science (PHY123H), engineering students (PHY110W), and biological and environmental science students (PHY132S). All the data collection occurred over a period of two semesters, between March and October 2003. Appendix B shows the data collection record and indicates:

the date of the video recording, the time of the recording, the class recorded, the number of students working on the tutorial and the tutorial task that the students were working on. A total of 45 video observations of the tutorials were made, each including an average of 3 tutor interactions per tutorial. The frequency of the interactions depended on the duration of the tutorial as the morning tutorials were forty five minutes, with the afternoon tutorials being three hours. The entire tutorial session was recorded. The tapes were then edited for the segments of interest for analysis, which were the periods of time just before a tutor was called to a group, during the intervention of the tutor and just after the tutor had left. A collection of these were then compiled into one tape for further analysis. The conversations among the students themselves and with the tutors were also transcribed.

3.2 Results from preliminary observations

When preliminary observations were made at the beginning of the study students were often working in groups of sixes (see Appendix B). After an analysis of seven video clips, it was evident that effective group work could not take place. The physical arrangement was making it difficult for students seated on opposite ends of a hexagonal shaped table to work together on their tutorials. Tutors were also limited in terms of facilitating effective group work since students seated in one group of six would often be doing different problems at the same time. There were often at least two subgroups within each group, with some students being marginalized from participation in the group. The number of students moving between groups was also high. It was then decided to insist that the group size be limited to three students. Although this was not always the case, most of the video observations made for the study were of students working in groups of three.

3.3 Analysis of the video data

A number of worksheet-based tools were developed to assist with the analysis of the video segments. These were used to analyse how students approached tutorial problems, what strategies tutors used to assist the students with the problems, and how students interacted with each other and with tutors in trying to solve the problems.

3.3.1 Problem analysis sheet

Discerning whether or not "learning" has taken place in a cooperative learning environment was deemed to be an essential aspect to this study. To this end, for each videotaped observation, the task on which the students were working was analyzed by means of a problem analysis sheet for the "critical components" that the students need to progress through the task. Figure 3.3 shows a problem analysis sheet and how it was used to unpack a tutorial problem for the critical components.

Department of Physics

Problem Analysis Sheet

Analysis completed by: __Reuben__

Class: _PHY132S_ **Tutorial no**: _1_ **Problem no**: _1 & 2_

A. The problem:

Question 1: A solid (dielectric) sphere of radius $R = 2$ cm has a uniform volume charge distribution $\rho = 10^{-6}$ C/m^3. Using Gauss' law, calculate the electric field both inside and outside the sphere.

Question 2 a: A spherical dielectric shell of inner radius **a** and outer radius **b** has a uniform volume charge distribution ρ (C/ m^3). Using Gauss' law, calculate the electric field everywhere (i.e. for $r <$ **a** ; **a** $< r <$ **b** ; $r >$ **b**)

B. List the main areas of physics content that are required to solve this problem:

Electric field:

inside a sphere ; $E = (K_e Q/R^3)r$

outside a sphere $E = K_e Q/r^2$; where r is the Gaussian radius

volume charge distribution $\rho = Q/V$

C. List the main problem solving procedures, skills and representations that are required for progress with this problem:

Draw representations of the fields both inside and outside the sphere to assist with identifying the Gaussian radius r.

Figure 3.3 *Problem Analysis Sheet used to unpack a tutorial problem into its critical components.*

The problem analysis sheet was designed based on the notion that students need to follow certain problem solving strategies in order to arrive at a meaningful solution for a problem. These critical components include both the conceptual knowledge and the mathematical and physics skills and procedures needed for the particular task. This analysis of the problem allowed the particular reason for which the students called the tutor to be identified, and hence whether or not the tutor was able to help the students progress meaningfully with the task.

3.3.2 Video analysis sheet

A worksheet was designed to facilitate the analysis of the video segments involving the intervention of tutors. Figure 3.4 shows the video analysis sheet which has been completed for one interaction between a group of students and a tutor. It is divided into the three phases of student-tutor interaction; pre tutor phase, tutor interaction phase and post tutor phase.

Although an analysis of non-verbal gestures and body language could also be made, verbal communication offered the main source of information used in the analyses. This kind of analysis is based on the assumption that a student could not contribute to the group in a sustained and meaningful way without a significant amount of verbal input (Buffler & Allie 1995).

The interaction of a tutor with the group was divided into three phases: the pre-tutor phase (from 2 minutes prior to the tutor being called), the tutor interaction phase and the post-tutor phase (until two minutes after the tutor left). The analysis of the pre-tutor phase included, how the three students are engaged (who is writing, who is talking, who is listening) and who decides to call a tutor, and why. Analysis was also made of the students' sense of need before they decided to call a tutor. The reason that the students called a tutor was put side by side with the actual nature of the problem as it appeared on the problem analysis sheet (Figure 3.3). This was in order to discern whether or not the students understood the tutorial problem and were following a logical problem solving strategy.

Analyses of the tutor interaction phase included noting who asked the initial questions, who takes initial control and whether the tutor involves all the students in the group. It also included investigation of whether the tutor had discerned the exact need of the group with reference to why the students called him. This made it possible to find out if the tutor's intervention was relevant to the reason he was called. The tutor's style was characterised as telling, questioning or Socratic. The Socratic approach is a technique that is seldom used in physics education, where an instructor asks a series of questions that lead students to examine the validity of their response to questions. It actively engages the learner and enhances critical thinking and students' construction of internalized meaning.

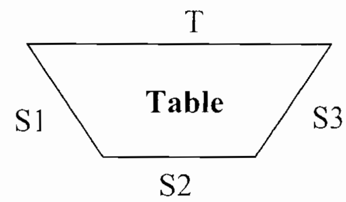
Analyses of this phase also included deciding whether the tutor's approach was content-oriented, i.e. the physics the question involved, or procedure-oriented, i.e. how to solve the problem. There was also an evaluation of whether or not the tutor used any means to find out if he was understood. This would be noticeable if the tutor monitored what progress the students made due to his interaction, or asked one of the students to explain to other group members what he had just said. The tutor's ability to facilitate engagement between all the students was also considered and characterised.

Analysis of the post-tutor phase focused primarily on the engagement of the students after the tutor had left. It was observed to see if the students have progressed with respect to the reason why they called the tutor.

The video analysis sheets were completed by making use of both the transcribed interactions and from direct observation of the video.

University of Cape Town
Department of Physics

Video Analysis Sheet



Seating arrangement:

Analysis completed by: Reuben

Date of tutorial: 22/07/2003 **Time:** 14:00–17:00 **Class:** PHY122S
Tutorial no.: 1 **Question no.:** 1 **Venue:** Room L
Tutor's name: N **Group no.:** 22 **Call no.:** 1

(M)ale or (F)emale: **S1**: M **S2**: M **S3**: M
Predominant language used by group: English

(A) Pre-tutor phase (from 2 minutes prior to tutor being called):

A.1 Engagement of individuals (pre-tutor):

	S1	S2	S3
Talking:	√		
Writing:			
Engaged"	√	√	√

A.2 Sense of need of group:
___ Check progress of group ___ Group needs information
_√_ Group stuck on problem Other: ________________________

A.3 Give particular details about why the tutor is called, with reference to Problem Analysis Sheet:
Group has the two equations for centripetal and Coulomb's force. They do not know how to use them to obtain charge.

A.4 Consensus to call tutor: S1:_√_ S2:___ S3:___
A.5 Who calls the tutor: S1:_√_ S2:___ S3:___

(B) Tutor interaction phase

B.1 Time that tutor spends with group: ___ minutes
B.2 Indicate position of tutor (T) on diagram above.

B.3 Style of initial contact:

	S1	S2	S3	T
Who speaks first?	√			
Who asks first question?	√			
Who takes initial control?				√

B.4 Initial tutoring style: _√_"Telling" ___ "Questioning"

B.5 has the tutor discerned the exact need of the group, with respect to A.3 above? ___ Yes _√_ No

B.6
Distribution of questioning by tutor:

S1	S2	S3
√		

B.7 Type of questioning: ___ to find where the difficulty is
___ Socratic (to draw out understanding)

B.8
Distribution of telling by tutor:

S1	S2	S3
√		

B.9 Type of telling: _√_ Procedural _√_ Content

B.10 Does B.7 and B.9 relate directly to the need of the students with respect to A.3 above? ___ Yes _√_ No

B.11
Engagement of individuals with tutor:

	S1	S2	S3
Talking:	√		
Writing:			
Engaged:	√		

B.12
Before leaving, the tutor checks understanding of :

S1	S2	S3

(C) Post-tutor phase (until 2 minutes after tutor leaves):

C.1
Engagement of individuals (post-tutor):

	S1	S2	S3
Talking:			
Writing:	√		
"Engaged"	√		√

C.2 Is progress made with respect to the reason why the group called the tutor (refer to A.3)? ___ Yes _√_ No

C.3
Students' need fulfilled (with respect to A.3):

S1	S2	S3

C.4 Tutor called for same difficulty:
___ Same tutor ___ Different tutor
___ Immediately ___ Later: ___ minutes

<u>Comments:</u>
Tutor only talked to the student who was asking questions
Tutor points the student to the formulae to use in order to rescue himself from explaining the situation.

Figure 3.4 *Video Analysis Sheet being used to analyse the interaction of students among themselves and with a tutor.*

3.4 Results

There are various ways in which students may interpret and attempt a physics tutorial problem. For example, students might try to discern that element of the problem that they presume relevant to their progress. A number of critical aspects might come into their focus of awareness while working on a problem. These critical aspects might be the result of the students' prior experience of working on similar problems or be related to some external factor or influence.

As mentioned in section 1.4, there is a phenomenographic claim (Marton & Booth, 1997) that learning is only possible through variation. This variation is related to the possible breadth and depth of the focus of awareness of the leaner. This extent of awareness is also known as the outcome space. Linder and Marshall, 2003, claim that discernment cannot take place without variation, and that the search for variation is driven by the particular structure of awareness brought to the learning situation. The structure of awareness broadly defines the learning context in its breadth and depth. When experiencing a phenomenon like learning, the aspects of a particular learning task which are discerned as part of a structure of awareness have been called the dimension of variation (Marton, 1998).

Cope, 2000, proposed that the validity and reliability of a phenomenographic analysis of learning is more meaningful if a structure of awareness is used as an analytical framework, where awareness can be characterised in terms of structural and referential aspects. The structural aspects are those that concern what one is doing at the time and with how one organises learning tasks. Ramsden, 1987, called this the act of learning. For students working on tutorial problems, this may involve identifying the physics concepts in a problem, or searching for the appropriate mathematical formulae to use.

The referential aspects are concerned with the intention with which one approaches learning. It relates meaning to the activity and may be described in terms of surface and deep approaches. Case, 2004, describes the surface approach as involving the simple reproduction of knowledge while a deep approach involves making sense of new information. In a group problem solving context, a deep approach may involve students trying to understand concepts underpinning a problem, while in a surface approach, the focus of awareness may consist of an isolated aspect of the content. Furthermore, in contrast to a surface approach, in a deep approach different aspects of a particular task may be held simultaneously in the focus of awareness. Prosser and

Trigwell, 1999, say that students who adopt surface approaches to learning are more likely to have learning outcomes of a poorer quality than those who adopt deeper approaches.

The analysis of the video data resulted in three categories of possible awareness of the students, which are presented in Table 3.1. These may also be regarded as three possible outcome spaces for students working in groups on tutorial problems, as observed from the video data. At any particular moment, a student's focus may have aspects of all the three, however one of these categories will dominate the other two. The aspects which are simultaneously present in awareness are known collectively as the thematic field (Marton & Booth, 1997). The thematic field is a collection of critical components used by students to solve a problem. Out of all aspects making the thematic field, a number of related aspects of a task will emerge to become the dominant feature in the thematic field thus direct students to a particular focus of awareness (see Table 3.1). The critical components that define the thematic field consist of the physics concepts and the procedures required for solving the particular problem.

In contemplating a phenomenon like a learning task, an individual will also be less aware, in a less focused sense of other aspects of the learning context, not necessarily related to the task. These non related aspects do not form part of the thematic field. The lower most row in the table categorized "external factors" exists outside the thematic field. Operating outside the thematic field shows a surface engagement with the task. Context, including the nature of the problem task, redefines which aspects of a phenomenon are in focal awareness and so different contexts will bring about a different thematic field.

The elements in Table 3.1 are hierarchical and are related to the students' level of engagement with the task. These levels became evident after characterising the various group actions associated with students working on different tasks in tutorials. The variation in group action was observed when completing the video analysis sheet (Figure 3.4). It appears that the particular level of engagement with the task is driven by the goals that the group want to achieve. The goals of a group, which direct the group's focus of awareness, subsequently lead the students to adopt a particular group action, which results in them being at some level of engagement in the hierarchy.

Table 3.1. *Categories of description of the variation in the focus of awareness of students working in groups on tutorial problems.*

Group goals	***Focus of awareness***	***Group actions***	***Engagement with task***
(a)Understanding the physics	Identifying the critical physics concepts underpinning the problem	Discussion around the concepts	Deep
(b)Getting the correct answer	Finding the right mathematical formula to use	Pattern matching the variables to a collection of available formulae	Medium
(c) Completion of the task as fast as possible and with minimal personal effort	External factors	Frequently calling the tutor for verification	Surface

The examples below illustrate the three categories (Table 3.1) characterising the variation in the students' focus as they interact with physics problems in a group problem solving context. They are grouped in the three phases of student-tutor interaction: the pre-tutor phase, the tutor phase and the post-tutor phase.

3.4.1 Focus of awareness: identifying the critical physics concepts

Here the students want to understand which physics principles are involved in the problem. They may attempt to make a link with their everyday experiences to obtain personalised meaning. This is noticeable when students use their everyday language in discussing the physics problem. Their conversation may be characterised by phrases and words such as, "what is the meaning of..." or, "explain''. The following example illustrates this:

(a) Example from the pre-tutor phase

S1: *What, how do you explain freezing?*

S2: *freezing...., eish!*

S1: *For freezing at higher altitude, of course the higher it takes the weaker.., now, how...*

S3: *Slower.*

S1: *Slower to freeze, meaning that ...*

S3: *It takes longer to boil.*

S2: *Ya.*

S1: *So are you saying that at Cape Town it takes...*

S2: *It is quicker.*

S1: *It's quicker to freeze in Jo'burg...*

S2: *No, no, no i think it is the same.*

S1: *It's slower to freeze in Jo' burg or is it quick to freeze?*

S2: *I think is the same anywhere, freezing that is it decreasing in pressure or temperature.*

Student **S1** starts the conversation by asking, "How do you explain freezing", suggesting that the student is looking for a meaningful understanding of the problem. Student **S1** also uses the phrase "meaning that" while student **S2** says "I think" twice, showing that they are focusing on trying to make sense of the situation.

(b) Example from the tutor interaction phase

In this case, as with previous one, the students focus on the physics which is seen as fundamental to solving the problem. In the conversation below students used the word "concept" more than once in their discussion with the tutor.

S2: *I think we have conflicting concepts. One concept is that when you bring two charges together ... the concept is that the charge tends to neutralise the positive charge. What happens is this, the* *resultant, what happens you have to divide by the resultant. You first have to get the resultant and divide by two.*

T: *You do not divide by two, what is the resultant, is it positive or negative?*

S3: *The resultant is positive.*

T: *You have to see.*

S3: *Because when you the resultant, you have two charges, 8 volts and the other one -4 volts.*

T: *Those are not charge, that's voltage.*

S2: *Coulombs.*

S3: *Coulombs all right, and then you bring them together. What I thought would happen is that the positive charge from there will neutralise that one, making this one (pointing on paper) zero. And that one+4 coulombs. This is neutral will...*

T: *Are you trying to say that we will no longer have the charge here, because this one is neutral?*

S3: *This one will remain neutral. So what, what do you think?*

T: *It is the question for you, how will I answer it for you. I don't want to answer you.*

S2: *If you have two conflicting concepts. The one is that when the charges come together, one will be neutralized. The other .....*

T: *Neutralisation seems to ....hold*

(c) Example from the post-tutor phase

This example shows students still trying to understand the physics involved after the tutor left the group. They are trying to understand the concepts of temperature, pressure and energy.

S3: *Less energy needed at high pressure.*

S2: *Low energy, low temperature.*

S1: *High pressure, less energy... energy is what?*

S3: *What, the water right, in Jo'burg does it boil at high temperature, cause we just know about the wait, we say it takes longer.*

S1: *What about low temperature?*

S3: *Less energy means low temperature hmm?*

S1: *Ok*

S3: *Here we are boiling right, we spoke about it takes faster or longer, what temperatures do we need, high temperature or low temperature?*

S1: *Like to boil?*

S3: *Like for boiling do we need high…*

S1: *Look at it from the pressure point, if the press is low, it means that …higher energy meaning that higher temperature right?*

3.4.2 Focus of awareness: finding the right mathematical formula

In this category students focus on finding a formula as the prerequisite to solving a physics problem. They presume that searching their text books, notes, memories or asking the tutor in order to identify the formula to use is the fundamental step in problem solving in physics. Once a formula is found, the students focus on the manipulation of variables, and substitution of the variables for the knowns and the unknowns.

(a) Example from the pre-tutor phase

The following conversation exemplifies this:

S3: *This expression is 21.*

S1: *Oh, oh ya.*

S3: *The problem, ok, when you take that, you put in here, but what about that.*

S1: *What?*

S3: *This is still unknown*

S1: *Can you try and solve that?*

S3: *That's what I'm working on.*

S1: *You now make V, V_2 the subject of the formula.*

S3: *Ya…… what's V_2?*

S1: *F...*

S2: *What about the y?*

Students talk in the mathematical symbolic language of y's, x's, v's and putting "that" in "there" without an indication that they attach any meaning or physical intuition to those variables.

(b) Example from the tutor interaction phase

Once again, the students prefer to converse about the physics in terms of formulae rather than concepts. For example, instead of using physics terms such as potential energy or mass, they would rather say *mgh* or *m*. They look for the relationship between the symbols in the formula and not the concepts involved. The following example shows this kind of interaction with a tutor:

T: *Kinetic energy. When it hits the pavement all the kinetic energy disappears, where does it go to?*

S3: *Into melting.*

T: *It goes into the hailstone and melts it. Ok so you know how much energy, kinetic energy the hailstone has, you know how much energy is used to melt it. Alright, go back instead, where does that kinetic energy come from?*

S2: *mgh.*

T: *mgh, so if you have energy mgh up here , becomes kinetic energy, kinetic energy all goes, becomes the heat gained by the hailstone, the only thing you don't know is the mass of the hailstone . If you let the mass be m, how much potential energy have you got up here?*

S2: *mgh*

T: *mgh, how much energy do you need to melt it, if you have mass m?*

S2: *m....L, What did, what did..?*

T: *m times, no change in temperature, it is melting?*

S3: *Lv.*

T: *m times L, so you got mgh = mL, m on both sides...*

S1: *Cancels.*

S2: *Cancels.*

The students show that they know what formula to use and correctly point out what variables cancel when the equation appears in a particular way. However, formulae are treated as mere equations to be solved mathematically with no reference to an underlying understanding of the physics quantities represented by the symbols.

(c) Example from the post-tutor phase

In the example below, the students look at what values of variables in the formula are given and which ones are not given, so as to substitute into a formula. The conversation below took place just after a tutor left:

S3: *Oh ok*

S1: *How were we supposed to know that? So this is (m_1 + m_2), in this case it is just m…*

S3: *Ah this change in thing, ya we have got m and we have the…*

S1: *It's just m ($V_{final} - V_{initial}$)*

S3: *Ya and we can put the, the we have got m we have got V_{final} minus $V_{initial}$, so we …*

S1: *And what V_{final}?*

S3: *We are looking for the … the, that's what we are looking for. We have got $V_{final} - V_{initial}$ so we taking this 27*

S2: *It's 2.7*

S3: *Oh 2.7 minus 2k*

S1: *Is that the change in momentum?*

S3: *Ya because, because it is equal to this and equals to that, (pointing to formula on paper), so we get this now.*

3.4.3 Focus of awareness: external factors

In this category students are not typically engaged. They want to finish quickly and leave, are lazy to search for new information or are just not interested. This is often apparent in cases where students show too much reliance on the tutor. They make comments like, "I don't know" or "I'm not sure". This is an example of a surface approach to problem solving, showing lack of active involvement from the students. In an interview, one of the tutors characterised these students in the following way, "they sit there with a blank face; you can see that the brain has not switched on. They are simply waiting for you to write the answer and that's all they want."

(a) Example from the pre-tutor phase

In the conversation below, a student raises her hand at the beginning of a tutorial to call a tutor to come and see if she is doing the right thing, before she has meaningfully engaged with the problem.

S3: *I'll start with my **a**, I will make sure I'm right though, come and help tutor. Tutor (calls for tutor). Is that a tutor, tutor! (S2 laughs).*

When doing the subsequent problem, the following interaction takes place.

S2: *So we have to use, we gonna use this to get that.*
S1: Ya.
S2: *The 0.4 has to be from here.*
S3: *But are you sure about that, or should we ask (a tutor)?*
S2: *Ask.*
S1: *You can ask just to make sure.*
*{**S3** raises her hand for a tutor}*
S2: *But then, but...*
S3: *Hmm...*
S2: *Ok, ok raise your hand.*

Student **S3** in particular wants everything to be done with assurance from a tutor. In the above two cases, she is the one who called the tutor and said that a tutor should be present to check the steps they use to solve the problem.

(b) Example from the tutor interaction phase

In the example below, students want the tutor to tell them everything and they will take all the information at face value. This can also happen when, after the tutor arrives he does all or most of the talking and the students are simply listening. They agree with what he is saying and most of the questions are answered with "yes".

S1: *Aah tutor, this thing if I ask about question 5, so could you please explain this question. We don't know how to calculate this.*

T: *Conservation of energy, you have done that. The energy that is due to height of the hailstone goes to melt the ice.*

S3: *Aah…*

(c) Example from the post-tutor phase

After the tutor has left, the students' discussion is focused on what the tutor told them. There does not appear to be an attempt on their part to internalize the meaning of what the tutor said. Their discussion resumes with questions like, "What did he say?" as opposed to something like, "What does he mean". Students even make follow up questions on subsequent tutors by telling them just what the previous tutor told them. The following example illustrates this:

S3: *What did he say?*

S2: *Neutralization seems to hold.*

S3: *Seems to be?*

S2: *Hold, as in the theory, the concept. Ya.*

S3: *So, but after neutralization what happens, this one does it becomes zero. This becomes four.*

S2: *Yes actually what happens then after is that, if this is neutralized it comes to zero, and this is -4. There cannot be an attraction between a neutral and a thing. Hence they can't share the charges.*

S3: *What did they induce, that's my, my main problem!*

In the example below from a separate interaction, students are talking to a tutor, but are eager to remind him that they doing what they are doing because a previous tutor told them so:

S2: *Here, eeh, we are struggling to find the height.*

T: *No no no, it's a horizontal tube.*

S1: *It's horizontal?*

T: *It's horizontal, so there is no variance in the height, the height does not change.*

S3: *What?*

T: *Ya.*

S3: *Some tutor did not tell us that.*

T: *What do you mean?*

S3: *She told us that it's changing.*

T: *No no. It's not, it's horizontal, it has varying various cross sectional areas.*

S3: *Ok*

3.5 Summary

The analysis of the video data suggests that students typically have one of three foci when working on a problem: understanding the physics, finding the right formula or getting task finished as quickly as possible (see Table 3.1). These three foci were evident in all the phases of student-tutor interaction and appear to be related to the level of engagement with the particular task (either deep, medium or surface), which in turn is related to the quality of learning taking place.

Awareness on the part of the tutor of these three categories becomes an important aspect with respect to the effectiveness of tutoring which takes place. If the tutor is able to discern the level at which the group is operating, then the chances are increased that he will be able to either maintain the focus of the students on the physics, or lift the focus of the students from the two lower levels.

4

The practice of tutoring

As the facilitators of cooperative learning tutorials, the tutors' role is to put into practice the educational expectations of the course instructor. The tutor has significant power to influence the focus of students working on the tutorial tasks by directing the discussion towards what he assumes to be significant for the students to progress with the task. It may be argued that it is desirable for the students to be engaged at a deep level with the tutorial tasks (Table 3.1) and that the tutor should take opportunities to lift students from working at lower levels to the top level of engagement. This can only be achieved if the tutor is able to discern the level that the students are working at, soon after arriving at a group. In responding to the expectation survey and interviews (see Chapter 2), most tutors asserted that students thought that their role was to help them with conceptual understanding and development of problem solving skills. This chapter will illustrate the main modes in which tutors have been observed to interact with students.

4.1 The tutor-student interactions at UCT

Tutors employ an array of approaches when interacting with students. Presented below are the main types of interactions between tutors and groups of students working in group problem solving tutorials that were observed in the video data. The four categories that emerged from the data have been termed: the "telling" tutor, the "formula-centred" tutor, the "detrimental" tutor and the "balanced" tutor.

4.1.1 The "telling" tutor

In this first category the tutor tries to help the students recognize the physics concepts involved in the problem they are working on, however he assumes a telling (transmission) approach to tutoring. Although the tutor may be convinced that the students need to understand the principles of physics involved in order to proceed with the problem, he believes that he should be the one doing most of the talking while the students listen and absorb what they are told. The following interaction illustrates this.

S1: *Are you going to explain this …*

T: *Hmm, I'm just trying to explain it differently (the tutor is now standing fully erect and scratching his head). But basically, for... for any rotational motion...there is always a force that is directed towards the centre of a circle.*

S1: *But you see, that's what you are saying, directed towards the centre.*

T: *Hmm...*

S1: *But now we are using centrifugal force, which is directed...*

T: *Oh centrifugal ok, now that is the opposite of centripetal. Centrifugal, If you say centripetal meaning towards the centre in that direction then centrifugal is in that direction*
{Showing opposite direction with his hand.}

According to Trigwell, 2000, this is an example of a teacher who has adopted an approach where the focus is on the teacher himself. In the situation above, the conversation ends, and the tutor leaves without finding out whether or not he was understood, or whether progress had been made with respect to why he was called. Furthermore, out of the group of three students, the tutor spoke only with one student (**S1**).

4.1.2 The "formula-centred" tutor

In this category the tutor's approach is characterised by focusing on finding the values for the knowns and unknowns after identifying which formula to use. He tries to lead the students through a symbolic and numerical approach to the problem, as illustrated below.

S1: *0.4.*

T: *0.4.*

S3: *For all of them?*

S2: *Ya.*

S1: *Ya.*

T: *But you don't need the force numerically, just derive the final formulae and then put the numbers.*

S1: *Oh!*

S2: *Oh!*

S3: *I don't understand, how?*

T: *Write the law of conservation of energy so, initially, ok we have that energy = potential energy + Kinetic energy, but kinetic energy = 0.*

S3: *Oh!*

S2: *Ok, at rest.*

T: *Ya.*

S3: *Hmm...*

T: *But they are released and accelerate towards each other, so kinetic energy is going to be ½ mv^2 ... ya. Then for potential energy is you put 0.4 and then calculate velocity.*

S2: Where?

S3: *For potential energy you do what?*

T: *What is the formula for potential energy?*

S3: *It's a ... potential energy, what's the formula?*

S2: *Potential energy is mv, for kinetic energy is ½ mv^2 right.*

S3: *Hmm...*

S2: *The other one is...*

S1: *mgh.*

S2: *mgh?*

S3: *Oh ya mgh (looks at tutor), so what do you do?*

S1: *So your h will be 0.4.*

S3: *your h?*

T: *Hmm...*

In the example above the tutor wants to give the students formulae for kinetic and potential energy although they did not ask for it. The tutor says to the students, "... just derive the formula and then put in the numbers", suggesting that from the tutor's perspective all that matters to the students in this problem is finding the right formula to use. This encourages the students to have a medium engagement with the task and the focus is simply in getting the correct answer. There is no indication that students will understand the physics even after completing this task.

The tutor's approach should have been to raise the students to a level where their discussion is focused on the relevant concepts. When answering the question, "for potential energy what do you do?", from student **S3**, the tutor might have asked, "What is the relationship between potential energy and kinetic energy?", rather than saying, " What is the formula?"

4.1.3 The "detrimental" tutor

In this type of interaction the tutor may or may not understand the questions the students are asking, but does not commit himself to helping the students directly.

S2: *I think we have conflicting concepts. One concept is that when you bring two charges together ... the concept is that the charge tends to neutralise the positive charge. What happens is this, the resultant, what happens you have to divide by the resultant. You first have to get the resultant and divide by two.*

T: *You do not divide by two, what is the resultant, is it positive or negative?*

S3: *The resultant is positive.*

T: *You have to see.*

S3: *Because when you find the resultant, you have two charges, 8 volts and the other one -4 volts.*

T: *Those are not charge, that's voltage.*

S2: *Coulombs.*

S3: *Coulombs alright, and then you bring them together. What I thought would happen is that the positive charge from there will neutralise that one, making this one (pointing on paper) zero. And that one + 4 coulombs. This is neutral will...*

T: *Are you trying to say that we will no longer have the charge here, because this one is neutral?*

S3: *This one will remain neutral. So what, what do you think?*

T: *It is the question for you, how will I answer it for you. I don't want to answer you.*

In the above example the tutor plainly refuses to deal with the students' queries directly and tells them, "It is the question for you, how will I answer it for you. I don't want to answer you". The tutor's response to the students' questions is frustrating their efforts to understand the problem.

This is an undesirable situation where a tutor is using excessive questioning in a condescending way to the students. The tutor resorts to countering whatever the students are saying or plainly refuses to answer any questions that may require direct answers.

4.1.4 The "balanced" tutor

Here the tutor uses an approach which may be characterised as having a sensible balance between questioning and telling.

S2: *Aah, number 5.*

T: *Yes? Ok what you are going to do in number 5, you are looking at a hailstone ha. It falls out from the sky... hits the pavement and it all melt...right. What does it need in order to melt?*

S1: *Temperature.*

S3: *Energy.*

S2: *Energy.*

T: *Energy, energy, energy, ok, now to melt it you need energy. What sort of energy does the hailstone have when it touches the pavement? Just before it actually makes that crash, what sort of energy does it have?*

S1: *Kinetic energy.*

T: *Kinetic energy. When it hits the pavement all the kinetic energy disappears, where does it go to?*

S3: *Into melting.*

T: *It goes into the hailstone and melts it. Ok so you know how much energy, kinetic energy the hailstone has, you now how much energy is used to melt it... Alright, go back instead, where does that kinetic energy come from?*

S2: *mgh.*

T: *mgh, so if you have energy mgh up here , becomes kinetic energy, kinetic energy all goes, becomes the heat gained by the hailstone, the only thing you don't know is the mass of the hailstone . If you let the mass be m, how much potential energy have you got up here?*

S2: *mgh.*

T: *mgh, how much energy do you need to melt it, if you have mass m?*

S2: *m....L, what did, what did..?*

T: *m times, no change in temperature, it is melting...*

S3: *Lv…*

T: *m times L, so you got mgh = mL, m on both sides…*

S1: *Cancels.*

S2: *Cancels.*

{Tutor leaves with student **S1** grinning at her satisfactorily.}

The above example illustrates a tutor attempting to make sure that students follow a sensible problem solving process. They move from one step of the problem to another after the tutor is satisfied that they understood the previous steps. The tutor is guiding the students to progress, by giving them some information and also allowing them to have valuable input in the conversation. Her questions follow up on previous responses given by students. This conversation is semi-Socratic (see section 3.3.2) and the students are actively involved in constructing their understanding.

4.2 Examples from other studies

4.2.1 The reflective practitioner (University of the Western Cape)

Linder *et al.*, 1997, developed a reflective practicum for a group of university physics tutors using an extension of Schonian-framed coaching experiences. Their aim was to stimulate reflection on the tutors' own learning when tutoring. The results were useful in characterising the role and experiences of tutors in physics group problem solving tutorials. They also suggested how Schon's notions of the role of reflection could be meaningfully extended to the context of student learning.

In their study, the tutor's practice, which was guided by a person with expertise in cooperative learning and knowledge of Schon's conception of reflective practice, was characterised as consisting of both reflection-in-action and reflection-on-action components. Three different modes of operation were identified for a tutor in action. These were the "follow me", "joint experimentation" and "hall of mirrors" approaches. Each of the approaches "calls for a different sort of improvisation, presents different orders of difficulty, and lends itself to different contextual conditions" (Linder *et al.,* 1997).

The "joint experimentation" approach involves the tutor experimenting together with students in search of reasonable and appropriate problem solutions. With the facilitator knowing the sphere of possible solution approaches, "joint experimentation" involves assessing and surveying the "practical and analytical" approaches which students might have difficulty with in the problem solution. "In joint experimentation, the [tutor's] skill comes first to bear the task of helping a [student] formulate the qualities she wants to achieve and then, by demonstrating or description, explore different ways of producing them. Leading the [student] into a search for suitable means of achieving a desired objective, the [tutor] can show her what is necessary according to the laws of phenomena with which she is dealing," (Schon, 1987).

The "hall of mirrors" approach involves the creation of a legitimate interchange of ideas, with students and the tutor continually shifting their approach when the tutor cannot immediately outline out how to solve a particular problem. It requires the tutor to be able to "authentically surface his own confusions" in order to illustrate how this initial inability to solve a problem can be turned into a meaningful learning situation. The hall of mirrors was thus suggested by Linder *et al.*1997 as the most ideal model which tutors should adopt.

The "follow me" approach involved telling and demonstrating how to solve aspects of a problem. It was only used when progress towards a solution became "extremely limited" while using the joint experimentation and hall of mirrors approaches.

Linder *et al.* reported an improvement in tutors' practice since the tutors had to assess and monitor the growth of their understanding of basic physics concepts during the tutorial sessions. This resulted in the tutors realising that they needed to begin in-depth reflections on the nature of their understanding and how they constructed these understandings (Linder *et al.*, 1997). Tutors were also observed to have changed personally due to this exercise. There was an enhanced confidence in themselves as competent teachers, leading to an improved ability to communicate effectively, coupled with a change in their own conception about their own role. Their reflections revealed tutoring as a sense-making practice as opposed to their prior ideas of tutoring as a telling activity.

4.2.2 Structured problem solving (University of Minnesota)

Heller *et al.*, 1992, have reported on extensive work on structured group problem solving tutorials. Their approach combines the explicit teaching of a problem solving strategy with a supportive environment to help students implement that strategy. The supportive environment is provided by having students practice solving problems in cooperative groups which are facilitated by tutors who are postgraduate students. The arrangement of their tutorial groups was done in a similar way as described by Johnson *et al.*, 1992, 1994 (see Chapter 1). Heller *et al.* suggest that a structured group problem solving strategy should include the following ingredients; a prescribed problem solving strategy, context-rich problems, cooperative group environment and an effective grading and testing system.

Their problem solving strategy was based on broad research evidence describing the nature of effective problem solving in physics. It was a hybrid of similar work reported by Frederick Reif, Joan Heller and Alan Schoenfeld (Heller *et al.*, 1992) and had five components. These were: visualizing the problem, describing the physics, planning a solution, executing the plan, and checking and evaluating. The first step involves translating the problem statement into a visual and verbal understanding of the problem situation. The second step requires students using their qualitative understanding of physics concepts and principles to analyse and represent the problem in physics terms. Thirdly, students have to translate the physics description into an appropriate mathematical representation of the problem. They then had to obtain a solution through a mathematical procedure. Lastly students are asked to check and evaluate their answer.

Heller *et al.* maintain that context rich problems focus students' attention on the need to use their conceptual knowledge of physics to qualitatively analyse a problem before beginning to manipulate equations. "Context-rich" problems can be understood as "short stories that included a reason for calculating some quantity about a real object or event". Some of the common characteristics of the context-rich problems were that: the problem statement could not always explicitly identify the unknown, more information may be available than needed to solve a problem, some information that could easily be estimated may be missing, and some reasonable assumptions may need to be made to solve a problem. Many problems were designed for use in tutorial and laboratory sessions.

The result of the above study suggested that teaching an explicit problem solving strategy and having students practice using the strategy in cooperative groups appeared to be an effective instructional approach. In responding to a questionnaire about their experiences students stated that, "the group work and problem solving is very helpful in understanding the material. The cooperation of students in each group, by discussing the problem and generating ideas, show how things are related." (Heller *et al.*, 1992).

5

Case studies

Presented in this chapter are five case studies selected from the video observation data. They illustrate how the analysis protocol, problem analysis sheet (Figure 3.3) and video analysis sheet (Figure 3.4) were used to interpret the video data. They highlight how students were approaching the problems, the different levels at which they were operating, how they interacted with each other and the different approaches that tutors used when interacting with the group.

In each case, students are observed working on a problem before they call a tutor, while the tutor is present and after the tutor has left. The analysis presented attempts to find a meaningful link between these different phases. The video summary in each case study relates the activities of the students during the three phases of the student-tutor interaction to the approach used by the tutor. Furthermore, suggestions are made with respect to what the tutor could have done to lift the students to the upper level of engagement (Table 3.1).

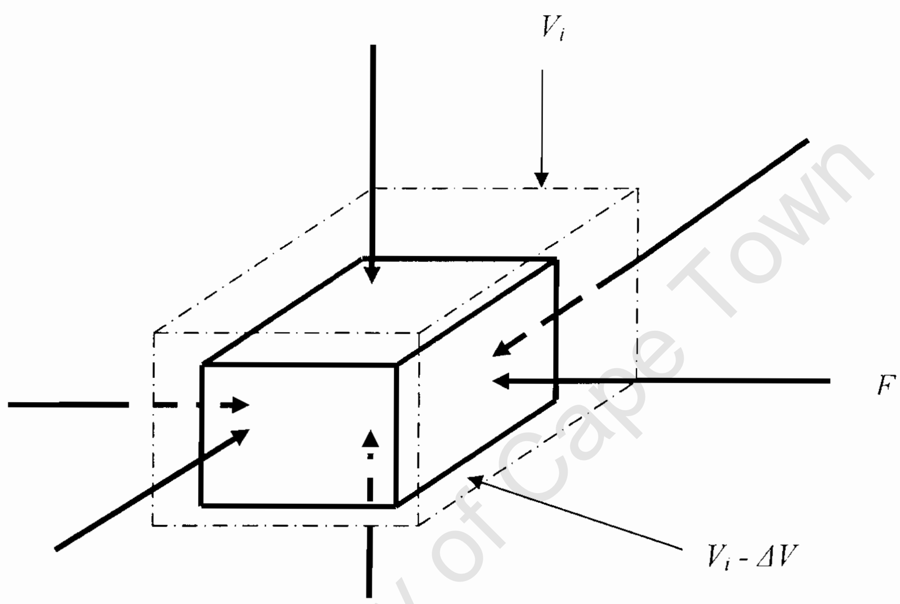
The presentation of Case Studies A and B includes all the information that was used for the analyses (the problem, the solution, the problem analysis sheet, the video transcript and the video analysis sheet). For Cases C, D and E, only part of the data set is presented, while the additional analysis appears as appendices.

5.1 Case Study A (PHY123H, Tutorial 4, Question 1)

5.1.1 Observation data for Case Study A

This problem requires the application of the bulk modulus as given by the ratio of the volume stress to the volume strain. Figure 5.1 below presents the problem and its solution.

A solid copper cube with edge L in vacuum is dropped into a liquid with density 1.2 g cm^{-3}. Calculate the bulk stress required to reduce the edge-length of the cube to $L/2$.



Bulk modulus B = − Volume stress/volume strain = $(-\Delta F/A)/(\Delta V/V_i)$ = $\Delta P/(\Delta V/V_i)$

$$\Delta P = -B\,(\Delta V/V_i)$$

$\Delta V = V_f - V_i$; Vi = L_3; Vf = $(L/2)^3 = L^3/8$

$$\Delta V = L^3/8 - L^3 = (-7L^3/8)$$

$$\Delta P = -B\,(-7L^3/8)/L^3 = 7B/8$$

Figure 5.1 *Problem task and solution for Case Study A.*

Attempting a problem of this nature requires the student to recognize and focus on a number critical areas, including the physics involved and the procedures required for solving the problem. The problem analysis sheet for this task is presented in Figure 5.2.

University of Cape Town
Department of Physics

Problem Analysis Sheet

Analysis completed by: _Reuben_
Class: __PHY123 H___**Tutorial no.**:__4__ **Problem no.**: _1_

A. The problem:

A solid copper cube with edge L in vacuum is dropped into a liquid with density 1.2 g cm^{-3}. Calculate the bulk stress required to reduce the edge-length of the cube to $L/2$.

B. List the main areas of physics content that are required to solve this problem:

Bulk modulus ; $B = -\Delta P/(\Delta V/V_i)$
ΔP = the bulk stress.
$(\Delta V/V_i)$ = the volume strain

C. List the main problem solving procedures, skills and representations that are required for progress with this problem:

Draw the situation showing how a cube can be compressed to one half its original size.
Volume of a cube = L^3
$\Delta V = V_f - V_i$

Figure 5.2 *Problem analysis sheet completed for Case Study A.*

Below follows an excerpt from the transcript of the students' conversation when working on the task. It includes the pre-tutor, tutor-interaction and post-tutor phases. Non-verbal activity is bracketed.

S3: *Stress equals 2 beta.*

S1: *Is that it?*

S3: *Of course we... the strain, we have the strain now, isn't it?*

S2: *Ya, so ya... we looking for stress ya!*

S3: *Why is L divided by 2? Why they do this here (pointing to paper)?*

S2: *No it's just, it's just ... 2 beta.*

S3: *Oh. I thought you said divided by 2.*

S2: *It is equal to stress equal 2B, 2B divided by...*

S1: *I don't understand what is B.*

S2: *That's the bulk stress.*

S2: *B is equal to 2 beta .... B is the bulk stress.*

S1: *That's what they want, the bulk stress?*

S2: *Ya.*

S1: *Stress, stress?*

S2: *Stress!*

S3: *Stress!*

S1: *This is stress, stress here (pointing to paper).*

S3: *P is equal to force over area.*

S2: *That's the volume.*

{S1 calls a tutor. Everyone waits for the tutor until he comes.}

S2: (to **S3**) *Tell him stress, we need stress.*

S3: *A lot of stress here ... ok stress is equal to ... strain ... no? We found the strain is equals 2 ... Because, I wanna know, I wanna know, what is that L/2? Like that?*

{S3 scribbles something on the paper, and all three students display confusion with respect to interpreting *L*/2.}

S1: *This is the edge, is it the edge?*

{The tutor nods his head to indicate agreement.}

S2: *The length...*

S1: *The length...*

S3: *The length...*

S2: *Ooh...*

T: *In other words in this problem, you going from a cube of volume* L^3 *to a cube of volume* $(L/2)^3$.

S1: *So this is like, it means ½, the sides of this, it's like compressed.*

T: *Cubed ... L^3 ... $(L/2)^3$.*

S3: *Ok, so what I can say is that ...*

S1: *So it is $\Delta L/2 * \Delta L/2 * \Delta L/2$, and that's the volume?*

{The tutor nods his head in agreement.}

S2: *Oh right, that's fine.*

S3: *But now we have... ok, so stress is force over area?*

{The tutor writes this down for them.}

T: *Now you can see, what you going to do is, you going to take every side and bisect all, you quickly going from this cube to this one...*

S3: *And so the cube, the cube, we assume the cube can be compressed?*

T: *Of course, why not, why can't a solid be compressed?*

S1: *This isn't a vector right?*

S3: *So how do you get the force?*

T: *How do you get the force?*

S3: *How do you get the force applied to ...*

T: *You take the liquid, you seal in on top and you push down...*

S1: *Ya , but this isn't a vacuum right?*

T: *In other words the pressure at the surface is zero and the pressure increases with depth, so down here, the cube is L/2 and here the cube is L . So you get this equation: $p = p_a + \rho gh$, and p_a should be zero ... ok!*

S2: *Thanks tutor.*

{The tutor then leaves.}

S1: *Ok, so, what L is, what is the strain... that we know. Calculate the average depth in the liquid at which the cube will have this edge length.*

S2: *Only here it ... bulk is stress over 2.*

S1: *What stress, what is the formula of stress, that is L over... stress, L over A.*

S2: *L/2, L/2, L/A...*

S1: *Surface area, what is surface area...*

S3: *How are we gonna get the force, pressure is the force applied right, is pressure force applied?*

S1: *We want this, we want this* (pointing to paper).

S3: *Ya ... but pressure is force applied on.* $P = P_1 + \rho gh$, *we must just find h.*

S1: *But what is h?*

S3: *What is h?*

S1: *L/8.*

S3: *L/8!*

S1: *Yes. L/2 * L/2 * L/2.*

S3: $L^3/8$.

S1: *Ya ...* $L^3/8$.

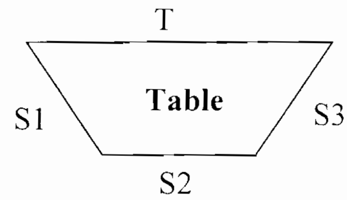
5.1.2 Analysis of Case Study A

The tutor-student interaction was analysed be means of a video analysis sheet (Figure 5.3). Of significant interest is when the tutor arrives at the group, whether he is able to discern the exact needs of the students, and after he leaves, whether the group is able to progress due to his intervention.

University of Cape Town
Department of Physics

Video Analysis Sheet

Seating arrangement:



Analysis completed by: Reuben

Date of tutorial: 30/09 / 2003	**Time**: 1400 -700	**Class**: P123 H
Tutorial no.: 4	**Qestion no.**: 1	**Venue**: Room L
Tutor's name:T	**Group no.**:41	**Call no.**: 1

(M)ale or (F)emale: **S1**: M **S2**: M **S3**: M
Predominant language used by group: English

(A) Pre-tutor phase (from 2 minutes prior to tutor being called):

A.1 Engagement of individuals (pre-tutor):

	S1	S2	S3
Talking:	√	√	√
Writing:	√		
"Engaged":	√	√	√

A.2 Sense of need:
--- Check progress of group --- Group needs information
_√_ Group stuck on problem Other:_ _ _ _ _ _ _ _ _ _ _ _ _

A.3 Give particular details about why the tutor is called, with reference to "problem information" sheet:

Group does not know what the question is asking for i.e what bulk stress is.

A.4 Consensus to call tutor: S1:_√_ S2:_ _ _ S3:_ _ _
A.5 who calls the tutor? : S1:_√_ S2:_ _ _ S3:_ _ _

(B) Tutor interaction:

B.1 Time that tutor spends with group: _ _ _ minutes
B.2 Indicate position of tutor (T) on diagram above.

B.3 Style of initial contact:

	S1	S2	S3	T
Who speaks first?			√	
Who asks first question?			√	
Who takes initial control?			√	

B.4 Initial tutoring style: _√_"Telling" _ _ _"Questioning"

B.5 Has the tutor discerned the exact need of the group, with respect to A.3 above? ___ Yes _√_No

B.6
Distribution of questioning by tutor: None

S1	S2	S3

B.7 Type of questioning: ___ To find where the difficulty is
___ Socratic (to draw out understanding)

B.8
Distribution of telling by tutor:

S1	S2	S3
√	√	√

B.9 Type of telling: _√_ Procedural ___ Content

B.10 Does B.7 and B.9 relate directly to the need of the students with respect to A.3 above? ___ Yes _√_ No

B.11
Engagement of individuals with tutor:

	S1	S2	S3
Talking:	√		√
Writing:			
"Engaged":	√		√

B.12
Before leaving, the tutor checks understanding of : None

S1	S2	S3

(C) Post-tutor phase (until 2 minutes after tutor leaves):

C.1
Engagement of individuals (post-tutor):

	S1	S2	S3
Talking:	√	√	√
Writing:			
"Engaged":			

C.2 Is progress made with respect to the reason why the group called the tutor (refer to A.3)? ___ Yes _√_No

C.3
Students' need fulfilled (with respect to A.3): **None**

S1	S2	S3

C.4 Tutor called for same difficulty:
___ Same tutor _√_ Different tutor
___Iimmediately ___ Later ___ minutes

Comments:
Students have no mental picture or an intuitive feeling for what is happening, they need to draw the situation first.
Tutor fails to get the exact needs of the group

Figure 5.3 *Video analysis sheet completed for Case Study A.*

In order to engage meaningfully with this question, the students need to have a clear mental picture of the physical situation, i.e. a solid copper cube of edge-length L in vacuum is compressed when placed in a liquid, to a cube having edge-length $L/2$. The students also need to understand that the pressure on this cube at a particular depth in the liquid is assumed to compress it equally on all sides. It also needs to be realised that there are no pressure differences exerted at different points on the cube due to the finite size of the cube.[1]

The group seems to be interacting well and are engaged with the problem. The three students start with a formula-centred approach to the question. They write down an equation for the bulk modulus and seem not to know what the bulk stress is and how to relate $L/2$ to the situation. They call a tutor and after a period of uncertainty concerning what to ask, one student simply enquires what $L/2$ is. All three students appear to be engaged with the tutor, who in turn appears to have listened to the students and has understood the question they asked.

The tutor tries to explain how a cube of sides L can be physically compressed to a cube having sides $L/2$. The students give the tutor a false sense of their understanding and the tutor employs no strategy to check on the understanding of the students or whether they are meaningfully equipped to progress with the problem. After the tutor leaves, the students immediately revert to their original formulae. Although they think they now understand what $L/2$ is, they still have difficulty to progress with the problem. The reason for this is that they still do not have a clear mental picture of the situation described in the problem and are therefore unable to relate the equations they have chosen to use with the physical situation.

5.1.3 What the tutor could have done in Case Study A

The first thing the tutor should have done was ask the students to explain to him what is going on in the problem. The students were having trouble with dealing with the equation for the bulk modulus since they had not clearly understood what was causing the compression of the block, and how. Their difficulties were possibly compounded by the fact that the bulk modulus was not explicitly mentioned in the problem and that the problem itself presents a physically impossible event. The students therefore are not focusing on the concepts. Instead they focus on isolated

[1] The question arises whether the author of this question thought about the unrealistic physics described in the problem.

pieces of the problem which they attempt to understand separately (Elby, 2001). With reference to Table 3.1, they are operating at a medium engagement with the task.

5.1.4 Further observation data for Case Study A

A while after the first tutor left, the group of students still do not know what to do. The following conversation takes place:

S2: *What is stress? Stress equals force.*

S1: *Now I don't understand... you see I asked what this, bulk stress is, but then we want this one, and the then what is this* (pointing to formula). *What is B? B equals stress over 2.*

S2: *What's the force?*

S3: *Pressure, that's what I say.*

S1: *What is the pressure here (points to question paper)?*

S3: *P_2 ... 5 over P_2 ... L.*

S2: *You see, that equation, that equation, what is your height, your average like pressure.*

{They all laugh at student **S2**.}

S3: *What's your average depth* (teasing student **S2**)?

The students can not progress at all. They are struggling with the expression for the bulk modulus. Student **S3** signals for a tutor and a different tutor arrives at the group.

S2: *Hi tutor.*

T: *You know this.*

{Although the students are working on question 1, the tutor points to question 4 on the paper.}

S3: *Ya.*

S2: *Ya.*

T: *You see it makes sense, because you find ... you see if this was at high pressure, what is going to happen?*

{The tutor holds a piece of paper showing high pressure on top.}

S3: *It will fall?*

T: *It will fall, now if the bottom is at high pressure ... so it makes the wings go such that air flows faster at the top than at the bottom.*

S3: *Ok.., but our problem was number 1! Basically this is what we did. Ok this is the equation.*

T: *It's this ...* $1.4 * 10^{11}$ (points to the board).

S2: *Is that the bulk stress?*

T: *Yes.*

S1: *They gave it to us!*

T: *That's the ... the bulk modulus.*

S3: *So what are we supposed to say here?*

S1: *So we can calculate stress as ... bulk times 2.*

T: *Bulk stress ... bulk modulus times bulk stress ... that's your bulk stress.* $\Delta V/V$, V_0 L^3 V *is a ... a ... L by 2 ...*

S3: $L^3/8$.

T: *That's right. So you see very easy, final velocity, initial velocity, you take it, you shrink it. So the change in volume divided by the initial volume, so that's your bulk stress. Ok be careful of the minus sign. So that is what is the bulk stress, the bulk stress is the pressure right?*

S3: *Ya.*

T: *And what is ... now that the bulk stress is the pressure that is what you have to find out. What is the bulk stress ... bulk modulus is* $1.4 * 10^{11}$ *, find the bulk strain.*

S2: *This is actually 1.4.*

{The tutor then leaves.}

S2: *This is 1.4.*

S1: *This is strain. We use this formula. The length is half, so we work out this, the volume, isn't it? So it's 2 times that* (points to the board).

S2: *Ya, we are talking about the volume strain eh?*

S3: *Are we just saying 2 times that volume?*

S1: *How do you get L now here?*

S3: *Now we have to do this, we have to do this* (points to paper).

S1: *So we say* $\Delta V/V$ *...* V_0 *is the... the initial volume.*

S2: *L*

S1: *Is L^3? You are right ... is L^3.*

5.1.5 Analysis of Case Study A (second tutor)

A while after the first tutor left, the group still do not know what to do. They are looking at the formula for bulk modulus and asking themselves what each of the variables stands for. They are confused and use the words "bulk stress", "pressure" and "force" interchangeably. The intervention by the first tutor was completely ineffective.

The second tutor goes straight to an explanation without asking the students what their problem was (or what question they were working on). He explains how Bernoulli's principle works on airplanes. After the students redirect the tutor to the question that they are actually working on, he focuses them on the formula and shows them the value for the bulk modulus (which is a constant). He tells them that the volume is going to change to $L^3/8$. He also tries to indicate on the formula what bulk stress is. The tutor then leaves without checking whether he was understood, or whether the students are able to progress meaningfully with the question.

5.1.6 What the second tutor could have done in Case Study A

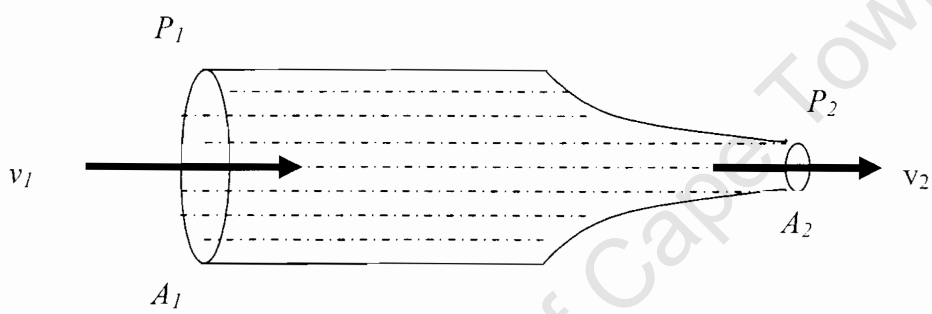
Discerning the exact needs of a group is a significant aspect of effective tutoring. The tutor should have let the students first tell him what their problem was. Employing a formula-centred strategy may help at times but it is also important for the tutor to make sure that this is preceded by appropriate conceptual understanding, which did not happen in this situation. The tutor should have also checked to see whether or not the students could meaningfully progress before he left the group.

5.2 Case Study B (PHY123H, Tutorial 11, Question 1)

5.2.1 Observation data for Case Study B

This question requires use of the Bernoulli equation, as well as the equation of continuity. The Bernoulli equation expresses the flow of an ideal fluid in a non-uniform pipe. Figures 5.4 present the problem task for this case and 5.5 presents the accompanying Problem Analysis sheet.

A Venturi tube may be used as a fluid flow meter (refer to your notes). If the pressure difference between points 1 and 2 of the inlet and outlet tubes, respectively is 21 000 Pa. Find the fluid flow rate in m^3s^{-1} given that the radius of the outlet tube is 1 cm while that of the inlet tube is 2 cm, and the fluid density is 700 kg m^{-3}.



The flow of an ideal fluid in a non uniform pipe can be expressed:

$P + ½ \rho v^2 + \rho gy$ = constant

Because the pipe is horizontal, $y_1 = y_2$

Bernoulli's equation becomes $P_1 + ½ \rho v_1^2 = P_2 + ½ \rho v_2^2$ (1)

From the equation of continuity, $A_1 v_1 = A_2 v_2$ (2)

$v_1 = (A_2/A_1\ ) v_2$

Substituting (2) into (1) gives: $P_1 + ½\rho (A_2/A_1\ )^2 v_2^{\ 2} = P_2 + \rho v^2$

$v_2 = A_1 \sqrt{} 2 (P_1 - P_2)/ P(A_1^2 - A_2^2)$

$A = \pi r^2$; $A_1 = \pi (0.02)^2 = 1.26\ 10^{-3} m^2$, $A_2 = \pi (0.01)^2 = 3.1410^{-4} m^2$

$(A_1^2 - A_2^2) = [(1.26 * 10^{-3})^2 - (3.14 * 10^{-4})^2] = 1.49 * 10\text{-}6\ m^2$

$v_2 = 1.26 * 10^{-3} \sqrt{} 2(21000)/700(1.49\ 8\ 10^{-6}) = 2.53\ ms^{-1}$ Flow rate = $\Delta v/\Delta t$

$= A_2 v_2 = 3.14\ 8\ 10^{-4} (2.53) = 7.94\ m^3s^{-1}$

Figure 5.4 *Problem task and solution for Case Study B.*

University of Cape Town

Department of Physics

Problem Analysis Sheet

Analysis completed by: __Reuben__

Class: _P123 H_ **Tutorial no.**: _11_ **Problem no.**: _1_

A. The problem:

A Venturi tube may be used as a fluid flow meter (refer to your notes). If the pressure difference between points 1 and 2 of the inlet and outlet tubes, respectively is 21 000 Pa. Find the fluid flow rate in m^3s^{-1} given that the radius of the outlet tube is 1 cm while that of the inlet tube is 2 cm, and the fluid density is 700 kg m^{-3}.

B. List the main areas of physics content that are required to solve this problem:

Application of Bernoulli equation:

$P_1 + ½ \rho v_1^2 = P_2 + ½ \rho v_2^2$; for Venturi tube ($y_1 = y_2$)

Continuity equation: $A_1v_1 = A_2v_2$

Flow rate is $\Delta V / \Delta t = A_1v_1 = A_2v_2$

C. List the main problem solving procedures, skills and representations that are required for progress with this problem:

draw the diagram of a Venturi tube showing: the direction of fluid flow with arrows, the relative sizes of the inlet and the outlet tubes.

$A = \pi r^2$, solving for v_2 from the Bernoulli equation,

$v_2 = A_1\sqrt{} 2(P_1 - P_2)/ \rho (A_1^2 - A_2^2)$

Flow rate : $\Delta V / \Delta t = A_1v_1 = A_2v_2$

Figure 5.5 *Problem analysis sheet completed for Case Study B.*

The following conversation takes place between the students and tutor.

S3: *This expression is 21.*

S1: *Oh. Oh ya.*

S3: *The problem, ok, when you take that, you put in here, but what about that?*

S1: *What?*

S3: *This is still unknown.*

S1: *Can you try and solve that?*

S3: *That's what I'm working on.*

S1: *You know make v, v_2 the subject of the formula.*

S3: *Ya .... what's v_2?*

S1: *F ...*

S2: *What about the y?*

{Student **S3** works out something on paper, then student **S2** calls a tutor, who arrives at the group.}

S2: *Here, eeh, we are struggling to find the height.*

T: *No, it's a horizontal tube.*

S1: *It's horizontal?*

T: *It's horizontal, so there is no variance in the height, the height does not change.*

S3: *What?*

T: *Ya.*

S3: *Some tutor did not tell us that.*

T: *What do you mean?*

S3: *She told us that it's changing.*

T: *No, no, its not, it's horizontal, it has varying various cross sectional areas.*

S3: *Ok.*

{The tutor then leaves.}

S2: *It doesn't make sense.*

S3: *Ya ... how does it look ?*

S1: *Tell, what ... there is no height.*

S2: *1 centimetre, that's 1 centimetre.*

S1: *Ok, look for this become 0, this thing goes away.*

{**S2** and **S3** nod their heads in agreement.}

S1. *So you say $P_1 - P_2$ ... aah, what is this ... you say this is equal to 21000 Pa.*

5.2.2 Analysis of Case Study B

The video analysis sheet completed for Case Study B is presented in Figure 5.6. In order for one to progress meaningfully with this question, the students need to understand what a Venturi tube and a fluid flow meter is, and what is meant by fluid flow rate. The students did realise that Bernoulli's equation is needed to solve the problem, but have not drawn a picture. None of the students refer to the equation of continuity, and they approach the problem by identifying what variables they have and don't have. They find themselves with two unknowns, the velocity at the outlet (v_2) and the height (y). They are convinced they should find v_2. (It is possible that they think that v_2 is the flow rate.) They see that the height is not given and they are confused. The students cannot progress since they do not know what a Venturi tube looks like. They need to draw a picture in order for them to see that the height is constant at both ends.

While the students are trying to work on the question, one of them calls a tutor. Another student tells the tutor that they are struggling to find the height. They all engage with the tutor who tells them that, "it is a horizontal tube and so the height does not change". The tutor makes no attempt to see if the students really understand before he leaves. He does not enquire to see if the new information he has given the group will help them progress.

Immediately after the tutor has left one student says, "It doesn't make sense". The students do not understand the relevance of "the height does not change". This tutor, who himself may have been operating at the upper level of Table 3.1, did not explicitly redirect the students to focus at that level.

5.2.3 What the tutor could have done in Case Study B

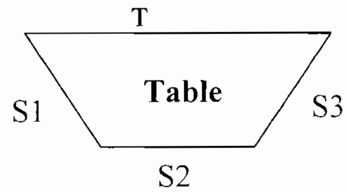
In order for the tutor to see whether the students understand, have a clear picture of the situation, and whether they will be able to make meaningful progress, the tutor should have asked them a question such as "What are you going to do with the height and do you have a clear picture of what is happening?" The tutor appeared not to have a series of appropriate questions at his disposal.

University of Cape Town

Department of Physics

Video Analysis Sheet

Seating arrangement:



Analysis completed by: Reuben

Date of tutorial: 09 / 10 / 2003 **Time** : 10 00 – 11 00 **Class:** P123 H
Tutorial no.: 11 **Question no.:** 1 **Venue:** Room L
Tutor's name: R **Group no.:** 42 **Call no.:** 1

(M)ale or (F)emale: **S1**: M **S2**: M **S3**: M
Predominant language used by group: English

(A) Pre-tutor phase (from 2 minutes prior to tutor being called):

A.1 Engagement of individuals (pre-tutor):

	S1	S2	S3
Talking:	√	√	√
Writing:			√
"Engaged":	√	√	√

A.2 Sense of need:
_ _ _ Check progress of group _√_ Group needs information
_ _ _ Group stuck on problem Other:_ _ _ _ _ _ _ _ _ _ _

A.3 Give particular details about why the tutor is called, with reference to "problem information" sheet:
The students need to know the Bernoulli expression for a venture tube.

A.4 Consensus to call tutor: S1 :_ _ _ S2:_ √_ S3:_ _ _
A.5 Who calls the tutor?: S1 :_ _ _ S2:_ √_ S3:_ _ _

(B) Tutor interaction:

B.1 Time that tutor spends with group: _ _ _ minutes
B.2 Indicate position of tutor (T) on diagram above.

B.3 Style of initial contact:

	S1	S2	S3	T
Who speaks first?		√		
Who asks first question?		√		
Who takes initial control?				√

B.4 Initial tutoring style: _√_"Telling" _ _ _ "Questioning"

B.5 Has the tutor discerned the exact need of the group, with respect to A.3 above? _√_ Yes ___ No

B.6
Distribution of questioning by tutor: None

S1	S2	S3

B.7 Type of questioning:
___ To find where the difficulty is
___ Socratic (to draw out understanding)

B.8
Distribution of telling by tutor:

S1	S2	S3
√	√	√

B.9 Type of telling: ___ Procedural _√_ Content

B.10 Does B.7 and B.9 relate directly to the need of the students with respect to A.3 above? _√_ Yes ___ No

B.11
Engagement of individuals with tutor:

	S1	S2	S3
Talking:	√		√
Writing:			
"Engaged":	√		√

B.12
Before leaving, the tutor checks understanding of : None

S1	S2	S3

(C) Post-tutor phase (until 2 minutes after tutor leaves):

C.1
Engagement of individuals (post-tutor):

	S1	S2	S3
Talking:	√	√	√
Writing:			
"Engaged":	√	√	√

C.2 Is progress made with respect to the reason why the group called the tutor (refer to A.3)? _√_ Yes ___ No

C.3
Students' need fulfilled (with respect to A.3):

S1	S2	S3
√		

C.4 Tutor called for same difficulty:
___ Same tutor ___ Different tutor
___ Immediately ___ Later: ___ minutes

Comments:
Tutor assumed a direct telling approach.

Tutor does not check if the group will progress, with the new information they have.

Figure 5.6 *Video analysis sheet completed for Case Study B.*

5.3 Case study C (PHY123H, Tutorial 11, Question 3)

5.3.1 Observation data for Case Study C

Figure 5.7 presents the problem task for this case. The question requires understanding of changes of states of matter as being due to change in temperature. The students need to understand how atmospheric pressure varies with height above sea level and how it affects changes of state (boiling and freezing) when the temperature changes. The problem solution, and problem and video analysis sheets are presented in Appendix C.1.

Water boils at 100 °C and freezes at 0 °C for sea level atmospheric pressure (Cape Town). At lower atmospheric pressure (e.g Johannesburg, where altitude is 1.6 km) the same water will boil and freeze at different temperatures. Explain this difference in detail.

Figure 5.7 *The problem task for Case Study C.*

The following conversation takes place between the students and tutor.

S1: *What, how do you explain freezing?*
S2: *Freezing... eish!*
S1: *For freezing at higher altitude, of course the higher it takes the weaker ... now ...*
S3: *Slower ...*
S1: *Slower to freeze, meaning that ...*
S3: *It takes longer to boil.*
S2: *Ya.*
S1: *So are you saying that at Cape Town it takes...*
S2: *It is quicker.*
S1: *It's quicker to freeze in Jo'burg.*[2]
S2: *No, no, no I think it is the same.*
S1: *It's slower to freeze in Jo'burg or is it quick to freeze.*
S2: *I think is the same anywhere, freezing that is it decreasing in pressure or temperature.*
S3: *Tutor!*

[2] "Jo'burg" is South African slang for Johannesburg.

{S3 calls a tutor who happened to be passing by.}

S2: *Number, number 2, we have the first part. That second part, freezing?*

T: *What did you say for the first part?*

S2: *We, we said, aah , in ... here in Cape Town the water boils quicker than in Jo'burg.*

T: *You think so?.*

S2: *Yes.*

T: *Why?*

S2: *Because in Jo'burg the pressure is high, so the counteraction of the pressure in the kettle ... like it takes long to reach the pressure.*

T: *Ok you are saying pressure is high in Jo'burg than Cape Town, why is that so?*

S3: *Because Jo'burg is at a higher altitude.*

T: *So ... High altitude means height above sea level, right?*

S3: *Yes.*

T: *Why do you think the pressure is higher when you go higher?*

S3: *It's actually lower.*

S2: *It's lower?*

S3: *Ya, the higher you go the lower the pressure, it's only when you go below the sea...*

S1: *That you go down pressure increases.*

S3: *Ya.*

S2: *Is it?*

S3: *Ya.*

S2: *Ok, Ok so it is the other way round.*

T: *Do you see it eeh, you see the relationship?*

S2: *Ya.*

T: *Between altitude and pressure.*

S2: *Ya, so you see, you go up, pressure goes down, a....*

T: *Do you know why?*

S2: *No.*

T: *Eeh, why do you think pressure is less when you go up? It is called atmospheric pressure right.*

S2: *Ya.*

T: *It is the pressure due to air molecules in the atmosphere or due to contents of the atmosphere. Now when you go up, the atmosphere, you are leaving some behind and less above you isn't it?*

S2: *Ya.*

T: *The atmosphere is not like an indefinite something, its finite, so when you go high, there is less atmosphere than, than when you are lower and so there is low pressure due to atmosphere when you go up.*

S2: *Ok.*

S3: *What about freezing?*

T: *That's why.*

S3: *Same, same principle.*

T: *Ya.*

S3: *But how is freezing related to pressure?*

T: *What is the difference between freezing and boiling, it is the change in state due to temperature right?*

S3: *Hmm...*

T: *So you need a particular amount of energy to effect that change in state. So the thing is in boiling you need more energy when there is more pressure to, to be countered. So it boils at higher temperature in Cape Town because the pressure is high, at low temperature in Jo'burg because the pressure is low.*

S2: *Hmm...*

T: *In so far as melting is concerned , when the pressure is high, when the pressure is high, do you need more or less energy to make the substance melt, or to make it freeze?*

S2: *When the pressure is high?*

T: *Yeah.*

S2: *You need less energy.*

T: *You need less energy. So less energy means what?*

S2: *Low temperature.*

T: *Low temperature ... sure?*

S3: *Hmm...*

T: *Is that so?*

S2: *Ya.*

T: *So at high pressure means lower temperature.*

S2: *Oh ya.*

S1: *Thanks.*

{The tutor leaves the group.}

S3: *Less energy needed at high pressure.*

S2: *Low energy, low temperature.*

S1: *High pressure, less energy ... energy is what?*

S3: *What, the water right, in Jo'burg does it boil at high temperature, cause we just know about the ... wait, we say it takes longer.*

S1: *What about low temperature?*

S3: *Less energy means low temperature?*

S1: *Ok.*

S3: *Here we are boiling right, we spoke about it takes faster or longer, what temperatures do we need, high temperature or low temperature?*

S1: *Like to boil?*

S3: *Like for boiling do we need high ...*

S1: *Look at it from the pressure point, if the press is low, it means that ... higher energy meaning that higher temperature right?*

5.3.2 Analysis of Case Study C

The students approach the question by looking at how slow or quick a substance takes to freeze or boil at either Johannesburg or Cape Town. They are trying to relate the length of time it takes to freeze or boil with the temperature required for that process. This is definitely not going to help them in this case, since the question does not state anything regarding the length of time water takes to boil in Cape Town or Johannesburg.

The students have not grasped the relation between the temperature at which a substance freezes or boils with atmospheric pressure. They call a tutor and ask him about freezing, saying that they have completed the first part on boiling. The tutor wants to know what they have done in the first part (boiling). This is a necessary intervention from the tutor as he is trying to understand what is confusing the students and why they are stuck. He wants to know their initial state. As the students try to explain what they said for the first part, it becomes clear that they did not understand the situation fully. One student tries to relate the amount of time that it takes to effect a change of state with the temperature at which that happens. He also incorrectly says atmospheric pressure is higher at Johannesburg (high altitude) than in Cape Town (sea level). The tutor uses a combination interchange of 'follow me' (telling) and 'joint experimentation' (Socratic) (Linder *et al*., 1997) approaches to draw out the students' understanding (see Section 4.2.1). He first tries to help the students to see the relationship between altitude and pressure and then explains to the students what atmospheric pressure is. The students appear not to be following in a clear way and after talking for a while, the tutor seems to confuse himself, and then leaves.

The students are left struggling with the 'new' concept of thinking of temperature in terms of energy. One student asks what energy is, while another tries to relate energy and pressure. The third student still tries to relate the temperature at which water boils to the length of time it takes to do so. This shows that though the tutor made an effort to show the students the correct picture, he was not successful in moving them from their initial incorrect thinking.

5.3.3 What the tutor could have done in Case Study C

The tutor should have given the students enough time to explain their thinking, before he proceeded to explain the situation from his own point of view. He could have helped them to see that their approach was not going to help them obtain a meaningful solution. Before he left the group, he should have asked one of the students to explain to the others what he had just said.

5.4 Case Study D (PHY123H, Group Task 1, Question 2e)

5.4.1 Observation data for Case Study D

Figure 5.8 presents the problem task for this case. In order to progress with this question, the students need to understand projectile motion in 2 dimensions as the vector sum of two simultaneous motions along the *x*- and *y*-axes. The problem solution, and problem and video analysis sheets are presented in Appendix C.2.

A ball is projected from the origin with initial velocity v_o, as shown. The initial speed of the ball is 50 m s^{-1}. Assume that g = 10 m s^{-2}. Complete the table bellow indicating the position components at one second time-intervals beginning at time zero when the ball leaves the ground.

Time (s)	x velocity (m/s)	x position (m)	y velocity (m/s)	y position (m)
0		0		0
1				
2				
3				
4				
5				
6				
7				

Figure 5.8 *The problem task for Case Study D.*

The following conversation takes place between the students and tutor.

S3: *So the acceleration ... which is 10, so we just, need this thing.*

S2: *Isn't it?*

S3: *That's velocity still, ya ... after 2 seconds.*

S2: *After 2 seconds, you see here we need F at 0 because ...*

S3: *Ya.*

{**S2** signals for a tutor, who comes to the group.}

S2: *Problem e.*

T: *Eeh?*

S2: *Eh, we don't give a ... displacement ...*

S3: *We figure that the initial ... each displacement is 0 since we are given the initial velocity, so we took where the projectile is launched to be 0.*

T: *Is that the origin of your coordinate axes?*

S3: *0.*

T: *Yes?*

S3: *So we have the acceleration ... we have the initial velocity, this is zero ... so we are not sure what this will be?*

T: *But isn't this the position after a certain time ... you are saying this is here at the beginning. This is where you choose the origin of your coordinate axes that is at $t = 0$, after 2 seconds, will the object still be there?*

S3: *No.*

S2: *No.*

T: *It will be somewhere else and that is the position that you want to calculate. And in order to calculate that you can only calculate the x-component using this equation and the y-component using that* (pointing to paper).

S2: *So the 2 seconds we substitute in there.*

T: *Yes, but first you have to find the missing terms here, what is the acceleration along the x direction?*

S2: *That one there is 10, 10 but in the i direction ... positive direction.*

T: *Aah, where is your, where is your i, where is your i direction?*

S3: *That is j.*

{**S2** shows a horizontal direction with his hands.}

T: *But this, is g* (pointing to question paper). *g is along the j direction. This is gravitational acceleration, g is along the j direction, what about the i direction?*

S3: *So in the j is 10?*

T: *Hello?*

S3: *How do we find the acceleration along the x?*

T: *Along the x ... if you have a projectile ... eeh, along the x-direction what is the acceleration?*

S3: *I think it is 0, because ... so it is 0.*

T: *Yes.*

S3: *So it is 0, these two* (points to the paper), *I think they have the same answer because along the x, it is the same.*

T: *Yes ... remember we did this calculation before.*

S3: *So it is constant.*

{The tutor leaves.}

S2: *What now?*

S3: *It stays constant, so velocity even after two seconds is the same.*

S2: *Is same for y also?*

S1: *No for y is different.*

S3: *No for y is different because it is dropping. in the x there is no change.*

5.4.2 Analysis of Case Study D

The question requires understanding that in the motion of a projectile, acceleration is downward in the vertical y-axis due to gravity and that there is no acceleration in the horizontal x-axis. Therefore after determining the x-component of velocity at time $t = 0$, the students should know that this will be the same for all other values of t.

The students have completed part of the table for time at $t = 0$ and $t = 1$ second. However, they cannot proceed at $t = 2$ seconds. One of them casually says the velocity should increase after 2 seconds and calls a tutor. Only two students (males) are actively involved in this problem while the third (female) looks on unclear as to whether she is following or not. The tutor comes and asks them to explain their question. He understands their problem and employs a questioning and telling strategy. He is also quick to point them (on the paper in front of them) to equations that they need to use in order to progress with the question. He makes them see that acceleration does not change along the x-axis and also assumes a formula-centred approach when he tells the students to look for missing terms. The tutor completely ignores the third student (female) in the group.

5.4.3 What the tutor could have done in Case Study D

This tutor used a balanced approach of telling and questioning after understanding the students' question. Although a formula-centred approach may be suitable option in some situations, in this case the tutor should have asked the students to find the relevant equations of motion instead of pointing them out to the students. The tutor should have noticed and made an attempt to see that the third student (female) was listening since she never interacted with the discussion.

5.5 Case study E (P123H: Tutorial 12 B, question 2)

5.5.1 Observation data for Case Study E

Figure 5.9 presents the problem task for this case. This problem requires the students to have a clear understanding of momentum. The problem solution, and problem and video analysis sheets are presented in Appendix C.3.

Impulse **J** is defined as the integral of force with respect to time and is also equal to change in momentum, as indicated below. The integral is evaluated over the time that the force is applied

$$\mathbf{J} = \int \mathbf{F}(t)\, \mathrm{d}t = \Delta\mathbf{p}\,.$$

Find the impulse of the force $\mathbf{F} = (1 - t)\mathbf{i} + t^2\mathbf{j} - \mathbf{k}$ between $t = 0$ and $t = 2$ seconds. What is the final velocity of a 4 kg object if this impulse is applied to it while travelling at 1 m s^{-1} in the **i**-direction?

Figure 5.9 *The problem task for Case Study E.*

The following conversation takes place between the students and tutor.

S2: *Here for no 2, we have done the integration of this thing, so we must find the final velocity.*
T: *Start again, look at me when you speak, you have found?*
S2: *We found the integration.*
T: *You have found the acceleration?*
S2: *Integration.*
T: *Oh you have done the integration.*
S3: *Ya, so we have to find the velocity.*
T: *So what... what, in this equation what does the integration tell you?*
S2: *They say it is equal to momentum, change in momentum.*
T: *So what you have done is that bit* (looking at their work) *isn't it?*
S2: *Ya.*

T: *Ok, now what they want to know is what the velocity is at the end of the 2 seconds, ok, what is the final velocity, ok look at that sentence now, it says impulse is equal to change in momentum. What is change in momentum?*

S1: *It's velocity.*

T: *What, no!*

S3: *It's the change, its final velocity minus initial velocity.*

T: *Now you are saying the impulse is equal to change in velocity. It says the impulse is the change in momentum.*

S2: *Ya.*

T: *What's momentum?*

S2: *mv.*

S3: *mv.*

T: *mv, so you want change in momentum which is mass times final velocity minus mass times initial velocity. You know what J is?*

S2: *Ya.*

T: *You just worked it out.*

S2: *Ya.*

S3: *Ya.*

T: *You know what mass is?*

S2: *Ya, ya.*

S1: *Ya.*

T: *You know what the initial velocity is?*

S2: *It's what we are looking for.*

T: *What!*

S2: *It's what we are looking for.*

T: *No it isn't! You are not looking for the initial velocity at all, read the question.*

S3: *Oh ... ok.*

S2: *Oh we are looking for the final velocity, the initial velocity we know.*

{The tutor then leaves.}

S3: *Oh, ok.*

S1: *How were we supposed to know that ?. So this is $(m_1 + m_2)$, in this case it is just m…*

S3: *Ah this change in thing , ya we have got m and we have the…*

S1: *It's just $m\ (v_{final} - v_{initial})$.*

S3: *Ya and we can put the, the we have got m we have got* v_{final} *minus* $v_{initial}$ *, so we…*

S1: *And what is* v_{final}*?*

S3: *We are looking for the ... the, that's what we are looking for. We have got* $v_{final} - v_{initial}$ *so we taking this 27.*

S2: *It's 2.7.*

S3: *Oh 2.7 minus 2k.*

S1: *Is that the change in momentum?*

S3: *Ya because, because it is equal to this and equals to that ...* (pointing to formula on paper). *So we get this now.*

5.5.2 Analysis of Case Study E

In order to proceed with this problem the students need to know that change in momentum (impulse) for a particle is caused by its change in velocity. Integration is a necessary mathematical skill to solve the problem numerically. The students successfully perform the integration but they cannot determine the velocity. Although they "correctly" followed the procedure, they did not relate this to their understanding of the situation. Their focus of awareness was identifying the right mathematical formula to use and then pattern matching the variables, which shows that their goal was getting the correct answer, leading to a medium engagement with the task (Table 3.1).

After calling a tutor and telling her that they have done the integration but cannot find the velocity, the tutor uses a balanced approach of questions and answers (see Section 4.1.4) to make the students understand that the product of their integration is momentum. However, she leaves without checking whether the students can progress with the question or not. The students fortunately do progress successfully with this question.

5.5.3 What the tutor could have done in Case Study E

Soon after arrival at the group the students tell the tutor that they have completed the integration. The tutor could have asked them, "Why did you do the integration?", or "How is that going to help you?". After completing the mathematical manipulation, the students do not know what to do with the result of their integration. Although the tutor used an effective approach to the students' question, it would have been even more useful if she had checked the students' understanding before leaving the group.

6

Discussion and conclusion

6.1 Contrasting the surveys, interviews and the video data

Students responded to the expectation survey (Chapter 2) by saying that the main purpose of small group physics tutorials is to assist them in developing conceptual understanding and problem solving skills. Tutors thought that students view the main purpose of small group tutorials to help them in that regard. The tutors' views about their own practice was confirmed in the interviews with them. The physics instructors also had a similar view about the purpose of tutorials in relation to the way they conceptualised their courses.

The results from the video observations showed that students in physics group problem solving tutorials call a tutor for a variety of reasons, but mainly when they are not clear how to proceed with a question. In many cases the student's need to get to the "right answer" is driven by a desire to finish the task at hand and not necessarily understand the physics involved. This can be attributed to lack of engagement with the task, which might be related to low motivation on part of the students. During his interview, one experienced tutor, a PhD student, said, "students should be self motivated, but what I'm noticing over the last two years is that students have been less and less motivated, on the tutoring side it's more and more... they sit there with a blank face, you can see that the brain has not switched on. They are simply waiting for you to write the answer and that's all they want."

Many students appeared to have a very casual attitude towards their own understanding of the physics concepts. Even when they said that they did not understand the question, more often than not they were referring to a procedure rather than the underlying physics involved. More specifically, the procedure they were focusing on was often a simple case of finding formulae to match the information given in the question. This kind of approach leaves the students discontented with respect to the purpose of problem solving in physics. Students do not seem to have a clear picture of the relationship between mathematics and physics, since the students' discussions were characterised by abstract reasoning in the language of mathematics and rarely involved thinking to any great depth about the physics involved. Their approach to physics is like that of mathematicians to mathematics, where they are only dealing with the structure of reasoning and they do not take care with what they are talking about, or whether what they say is physically realistic (Feynman, 1992).

The tutors, on the other hand, have been observed in most cases to focus directly on what the students are asking for. The different approaches used by tutors can be categorised into "telling", "formula-centred", "detrimental" and "balanced" approaches, with the formula-centred approach being the most common. This is in stark contrast with what the tutors claimed students thought their role was in their surveys and interviews, i.e. to assist the students in understanding of concepts and in developing problem solving skills. In nearly all the examples of tutor interactions captured on video, the tutors did not manage to stand back from the situation and deal directly with the conceptual understanding of the students. Although all the tutors would claim that using appropriate diagrams is crucial to unpacking a problem, hardly any of the tutors, when actually interacting with the groups, focused on the need to use a diagram, thereby suggesting a serious lack of reflection on their own practice.

In summary, what the students and tutors claim to be their expectations of physics tutorials is very different from what was observed to happen in practice. DiSessa, 1993, calls this a casual sense of mechanism, when people gradually acquire an elaborate sense of how things are, what sort of events is necessary, likely, possible or impossible, without deep reflection on what is actually happening.

6.2 Implications for tutoring

The present data, coupled with the result of others (Heller *et al.*, 1992, Linder *et al.*, 1997) suggest that tutors can operate in a number of ways in a physics cooperative learning tutorial. The optimum mode is that the tutor should be able to move students to a deep engagement (Table 3.1) with the task. This is based on the notion that making sense of new information and understanding can only occur at that level. However, tutors may be restricted in the approach they can adopt by the style of questions that exist on the tutorial sheet, the type of assistance that the students may be asking for, and the broader context, which Redish, 2003, calls the hidden curriculum. This he describes as the set of ideas and expectations that students bring to class about the nature of their own learning, the nature of the discipline they are learning, and what they think they are expected by the instructor to do in class.

6.2.1 Style of tutorial questions

The nature and style of the tutorial problem appears to be a major underlying factor in constructing useful interactions in group problem solving tutorials. The design of an effective problem solving tutorial requires more than just assigning a set of back-of-the-textbook type problems to the students. In preparing tutorial questions, consideration needs to be given to; what the purpose of the tutorial is, reasons why a question is set, what it involves to solve the question and what the students will achieve after completing the question. For example, Case Study A (Chapter 5) shows a situation where students are struggling to make sense out of a physically impossible situation. This problem requires the application of the idea that the bulk modulus is given by the ratio of the volume stress to the volume strain. The question assumes that the students will understand that the pressure on the cube at a particular depth in the liquid will compress it equally on all sides, and that the finite size of the cube should be ignored.

In view of the fact that students are sometimes not able to distinguish between physics procedures and physics concepts, the role that mathematics plays in physics needs to be explicitly highlighted. This resonates with what Hestenes, 1992, calls "modeling games". He claimed that a major focus of the physics teaching enterprise should be to teach explicit modeling principles and model deployment to describe physical phenomena. Allie and Buffler, 2003, in an introductory chapter of their tutorial manual for students, say that, "it is useful to think of physics in terms of a process by which an attempt to model a phenomenon by identifying its most important aspects and then reducing, what is usually a complex system in the real world, to a more simple, idealized system which can be treated mathematically".

Tutorial questions have to be varied in scope, in a manner that will capture the complexity of way of experiencing phenomena like a learning task (see Section 1.4). The dimensions of variation in the questions should aim at the possible outcome spaces, or focus of awareness for the students as illustrated in Table 3.1. A tutorial designed in this way will be satisfying the phenomenographic claim, that learning is only possible through variation (see Sections 1.4 and 3.4)

6.2.2 Tutor training

When approaching to assist a group, tutors need to have a "question bag" from which they can select the most appropriate opening questions such as, " what question are you working on?", "what are you doing?", and "how is it helping you?" Tutors need to discern the right approach to use under different conditions in order to shift the focus of students to the upper level of engagement (Table 3.1). This might involve engaging the students in a discussion around the critical issues in the problem. It also requires the tutor to know when to write for the students, assist with drawing a diagram, answer or ask a question, or refer them to either their notes or text.

Tutors need to strike the right balance between questioning and telling with the intention being to engage the students deeply with the task. They need to be able to help students distinguish between physics concepts and procedures. The problem analysis sheet (Figure 3.3) might be a useful tool for tutors to "unpack" tutorial questions for their critical components, i.e. the main areas of physics content that are required to solve the problem, and the main problem solving procedures, skills and representations that are required.

Tutors also need to monitor whether everyone is involved, everyone is talking and that none of the students in the group is left out. Before the tutor leaves a group, he needs to make sure that he has been understood and that students will progress as a result of his intervention. This can be achieved if the tutor asks the students to reflect back to him how the new information is going to help them. In a group problem-solving context, the tutor should facilitate active participation from all group members, by being able to assess whether or not one student is controlling the group or whether a student is being passive.

In summary, the tutor needs to be a reflective practitioner (Schon, 1987), by being constantly aware and critical of his practice. Linder *et al.*, 1997, refer to the kind of reflection that a tutor should employ in a tutorial session as reflection-in-action (see section 4.2.1). This they claim is when tutors are constantly thinking of the best question to ask, and whether that will lead the students in the right direction.

A proper facilitation of a tutorial with the above components cannot be made on assumptions that everyone knows what is expected of them. It implies that tutors need to be appropriately prepared so that they synchronize well with the model and the purpose of the tutorial. The lecturers, tutors and students did agree in the survey (Section 2.1) that rigorous tutor training would improve the tutors' practice.

6.2.3 "The whole"

Marton and Booth, 1997, claim that when "the whole" is missing, then learning is likely to be ineffective. The ideal situation is that everybody involved should have the same big picture in mind and that nothing should be left to assumptions. The students need to be made well aware of what is expected from them and why, and be sensitised as to why they are being asked to work cooperatively. Students need to know the purpose of problem solving and also be made aware of their own learning (Linder *et al.,* 1997).

Any instructional activity that does not relate to the expectation, type and mode of assessment that is being used is a futile exercise. The mode of assessment used in tests and examination is a significant factor in guiding students to adopt a particular learning strategy. All kinds of activities taking place in the group problem solving tutorial should have a direct link to what is expected in tests and examinations. Even if students may be doing well in examinations, studies such as the force concept inventory (Hestenes, 1992) and concentration analysis (Bao & Redish, 2001) show the kind of misunderstanding and lack of concepts students have in responding "correctly" to test questions.

Finally, instructors, tutors and students should see group problem solving tutorials in the broader context, i.e. how they coexist with laboratories and lectures. Lecturers need to be in regular contact with tutors in order to keep them up to date about details of particular courses so that students receive a unified message concerning their role. There is need for pre-tutorial meetings, where tutors, together with the lecturer in charge discuss not just how to solve problems, but more importantly, what questions to anticipate from students and how to respond to those questions. In responding to a question from the interviews, a tutor who realised the need to bridge the gap between lectures and tutorials said, "You can't expect the tutor to explain all the work from scratch, it's frustrating for the tutor and it puts the tutor in a bad mood".

The objectives and goals of components of a system and the system as a whole have to be explicit. Each tutorial task should have a clear and explicit objective. The sum of the objectives of the individual tutorial tasks should equal and synchronise with the objective of the tutorial. The clarity of this situation itself redefines the role that the students, tutors and lecturers play in running effective physics cooperative problem solving tutorials. Meaningful learning will thus be achieved only when students understand the whole as well as its parts. Smith *et al.,* 1991, say that motivation to learn is alterable; it can be positively or negatively affected by the task, the environment, the facilitator and the learner. Learning is more effective and efficient when the learners have explicit, reasonable, positive goals and when their goals fit well with the instructor's goals.

6.3 Summary of results

The present results indicate that students working on tutorials have their focus of awareness directed so as to achieve one of the following three goals: understanding the physics, finding the right formula to get the answer or getting the task finished as quickly as possible. These foci are directly related to the students' level of engagement with the task, which may be characterised as deep, medium or surface. The level of engagement with a particular task (either deep, medium or surface) was in turn found to be directly related to the quality of learning taking place. The type of activities that students perform in a tutorial setting is however influenced by their expectation of what physics is, what it takes to learn physics and what the instructor expects them to do in a cooperative learning physics tutorial session.

Tutors, on the other hand, were found to employ a range of approaches when assisting groups of students. These were characterised as the "telling", "formula centred", "detrimental" and "balanced" approaches. Tutors were observed in most instances to engage directly with what the students asked of them, which in many instances was related to a formula-centred approach to the problem. Tutors were observed to be lacking a rigid problem solving strategy as well an approach to facilitate evocative learning. Most tutors were observed to be unable to reflect upon their own practice and hence facilitate a meaningful interaction with the students.

6.4 Preliminary intervention at the University of Cape Town

The Physics Department at the University of Cape Town has been using group problem solving tutorials for over a decade. Although there are slight variations in the ways that the tutorials are run which depend on the class, the instructor involved, and the particular tutors, there has recently not been a holistic attempt to improve the quality of these tutorials.

In response to the present work, and as a step towards meaningful tutor training, two tutorial instruments were designed, one for the tutors (Figure 6.1) and one for the students (Figure 6.2). The tutors' instruction sheet was designed to be used in conjunction with a pre-tutorial discussion, which aimed to provide tutors with some tools, which might make their practice more meaningful. The cartoon for the students (Figure 6.2) was designed to suggest to them a brief motivation for why they are being asked to work cooperatively and provide them with some tools to interact more effectively amongst themselves and with the tutors. The instruments were piloted at the start of 2004. Each student was given the cartoon at the start of the course, and the tutors' instruction sheet was used as part of a pre-course tutor training meeting. Although this present study did not extend into evaluating the effectiveness of this intervention, initial indications were that both the tutors and the students found these sheets to be useful.

6.5 Future work

Although our tutors and students appeared to have a reasonable idea of what is expected of them in physics group problem solving tutorials, in practice a completely different set of actions took place. Future work should therefore concentrate on finding out the reasons why both students and tutors cannot put into practice what they both profess to be the right thing to do.

As much as the need for effective tutor training has been highlighted, there is also a necessity to find out what type of sensitisation students should be exposed to in order to maximise the benefits offered by group problem solving tutorials. Further work should therefore also focus on the views that students have about their own learning strategies in these tutorials.

University of Cape Town
Department of Physics

Things to think about when you are tutoring physics small group tutorials.

Before the tutorial.
Get the questions in good time.
Work out all the solutions.
Meet with all the other tutors before the tutorial to check on common strategies to the problems. It's no use if you cannot agree on how to do a question amongst yourselves!
[This requires more planning]: Check that what you tell the students is in line with what the lecturer intends. [How will you achieve this?]

During the tutorial:
Check that the students are working in groups of three (not 4, 5, 6, ...)
Look for dysfunctional groups ... motivate the students to focus on the task at hand.
Keep circulating. Don't stand still, even if you are not being called.
Don't hang together with other tutors.
Don't hang out in a small region of the room. Circulate widely.
Use simple language when talking to students.
Be enthusiastic and encourage the students. Don't be condescending.
Check that the students are using their lecture notes.

Helping a group:
Think about your general strategy as a tutor. What is your role? Be careful to strike the right balance between giving answers and giving guidance. You don't want to frustrate the students and you want the tutorial to be a meaningful learning experience for them. If the students don't find the activity useful, then they won't take the time seriously. Be careful not to spend a long time (more than 5 minutes) with a particular group.

There are generally two types of activities:
... checking on a group without being called, and responding to being called by a group.

Checking on a group without being called.
Look and see what the group is doing.
Is everyone involved? Is everyone writing?
Is one of the three students being left out?
Go up to the group and ask them:

What question are you working on?
What are you doing?
Why are you doing it?
How is it helping you?

Don't leave the group until you think things are satisfactory.

Responding to being called by a group.
When you approach a group, try to leave the control of the situation with the students.
Don't make a grab for a pen.
Make sure all three students are focused on the conversation.
Ask the students which question they are working on !
Then ask them **what their question is.**

Be careful of "We are stuck" or "We don't know what to do."

The trick is for you to ascertain what their real difficulty is and to help them get to a position where they can progress meaningfully.

Some useful questions to ask include:

What number are you working on?
What is your question? ... and listen carefully.
Explain to me what is going on in the question. ... don't focus immediately on the formulae
What physics is important here?
Would it be useful to draw some type of diagram?

Some questions to avoid completely:

What equation must we use here?
... ones which result in "yes" or "no" answers.

Before you leave the group:

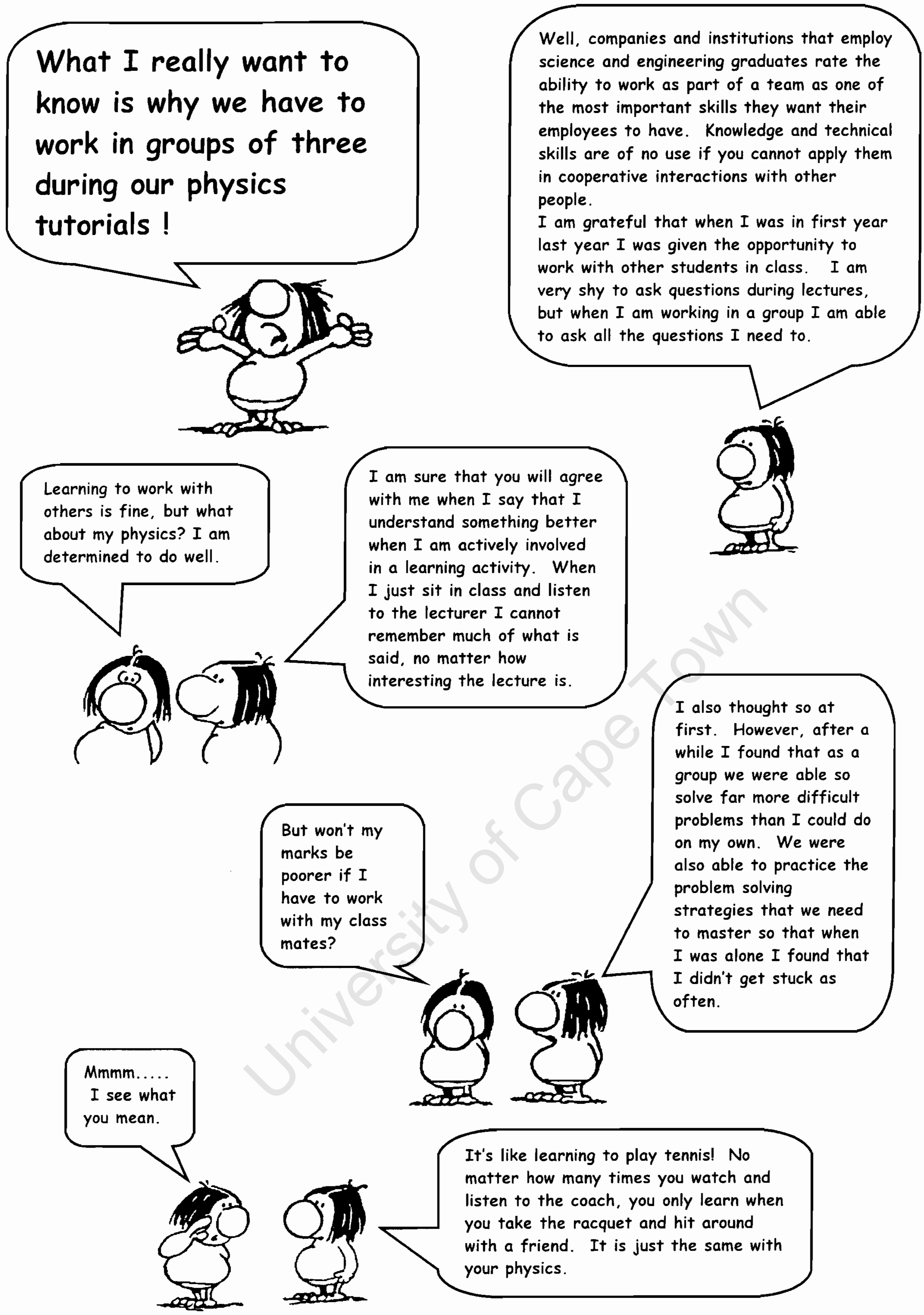
Ask the students whether everyone understood what you explained.
Check on all three students.
Ask one of the students to explain back to you what just went on.

Check on the same group about 5 minutes later to see if everything is OK.

The most common problem with tutor-student interactions occurs when the tutor assumes (incorrectly) that the students have a particular understanding. This generally occurs in two areas:

(i) The students have not understood the problem situation ... and both tutor and students are focusing on equations. Always make sure that the students understand what is going on in the question before you go for mathematics.
(ii) The students have not understood what the tutor has explained ... the tutor leaves the group without checking. The students have given the tutor a false sense of understanding. Ask the students to reflect back to you what you have just explained to them.

Figure 6.1 *Guidelines given to physics tutors.*


What I really want to know is why we have to work in groups of three during our physics tutorials !
Well, companies and institutions that employ science and engineering graduates rate the ability to work as part of a team as one of the most important skills they want their employees to have. Knowledge and technical skills are of no use if you cannot apply them in cooperative interactions with other people.
I am grateful that when I was in first year last year I was given the opportunity to work with other students in class. I am very shy to ask questions during lectures, but when I am working in a group I am able to ask all the questions I need to.
Learning to work with others is fine, but what about my physics? I am determined to do well.
I am sure that you will agree with me when I say that I understand something better when I am actively involved in a learning activity. When I just sit in class and listen to the lecturer I cannot remember much of what is said, no matter how interesting the lecture is.
But won't my marks be poorer if I have to work with my class mates?
I also thought so at first. However, after a while I found that as a group we were able so solve far more difficult problems than I could do on my own. We were also able to practice the problem solving strategies that we need to master so that when I was alone I found that I didn't get stuck as often.
Mmmm..... I see what you mean.
It's like learning to play tennis! No matter how many times you watch and listen to the coach, you only learn when you take the racquet and hit around with a friend. It is just the same with your physics.

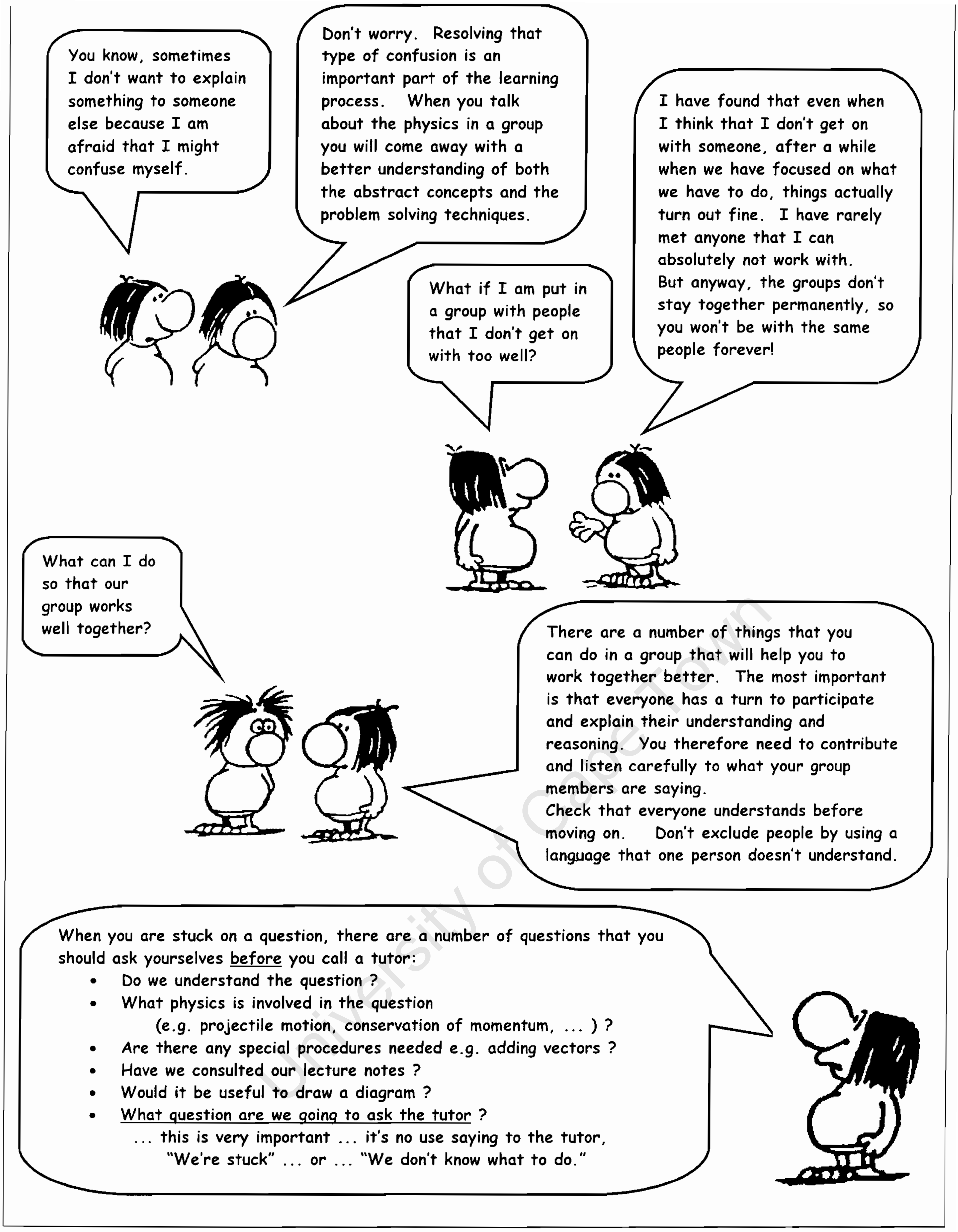


Figure 6.2 *Guidelines given to physics students.*

Appendices

Appendix A.1
CAPTEX expectation survey

University of Cape Town
Department of Physics
Cape Town **P**hysics **T**utorial **Ex**pectation Survey

Circle your course code:

PHY121F/122S PHY131F/132S PHY110W PHY123H PHY124F PHY134S

Below are 25 statements, which may or may not describe your beliefs about first year physics at UCT. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree

Answer the questions by circling the number that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple.
If you don't understand a statement, then leave it blank.
If you understand the statement, but have no strong opinion, then circle 3.

A	1	One of the main skills for me to get out of Physics I is to learn how to solve physics problems.	1 2 3 4 5
A	2	When learning physics, I find it helpful to make explicit connections to the everyday world.	1 2 3 4 5
B	3	I think that "problem solving" in physics basically means matching problems with equations and then substituting values to get a number.	1 2 3 4 5
C	4	I think that working with other students in small group problem solving tutorials is an effective way for me to learn physics.	1 2 3 4 5
A	5	I spend a significant amount of study time trying to understand the derivations or proofs given in class.	1 2 3 4 5
C	6	I think that it is important for the lecturer to explicitly develop problem solving strategies in lectures.	1 2 3 4 5
B	7	I use my physics textbook regularly.	1 2 3 4 5
A	8	When an exam or test is marked, most marks should be allocated to the final answer only.	1 2 3 4 5
C	9	I find that the best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail.	1 2 3 4 5

C	10	I think that it is necessary for the lecturer to meet regularly with the tutors in his or her class in order to prepare them for tutorials.	1 2 3 4 5
B	11	The main role of the tutor in a tutorial is to assist the students with conceptual understanding, rather than providing us with the right answers to the specific problems.	1 2 3 4 5
A	12	The physics lecturer should think about his or her own experiences as a student and relate them to the topic being taught in lectures.	1 2 3 4 5
C	13	In order for small group tutorials to be effective, the tutors need to be appropriately trained.	1 2 3 4 5
C	14	I think that spending a lot of time (half an hour or more) working on a single physics problem is a waste of time.	1 2 3 4 5
B	15	I think that I do not have to understand the concepts behind the equations used to solve a particular problem.	1 2 3 4 5
C	16	When first year physics exam problems are marked, a significant emphasis should be placed on the problem solving method used by the student.	1 2 3 4 5
A	17	An important skill for me to get out of Physics I is to learn how to reason logically about the everyday world.	1 2 3 4 5
C	18	The lecturer should attend the afternoon tutorials for his or her class for at least part of the time.	1 2 3 4 5
B	19	I think that physics has little relation to what I experience in the everyday world.	1 2 3 4 5
B	20	I think that physics tutorials are very useful.	1 2 3 4 5
A	21	The most crucial thing in solving a physics problem is finding the right equation to use.	1 2 3 4 5
B	22	I think that if I have all the required equations on my formulae sheet, then I will do very well in the exam.	1 2 3 4 5
C	23	When I solve a physics problem, I explicitly think about the concepts that underlie the problem.	1 2 3 4 5
A	24	Physics should help me better understand situations in everyday life.	1 2 3 4 5
A	25	It is possible to pass Physics I without understanding physics very well.	1 2 3 4 5

If you want to make any comments about your experiences in physics tutorials, then you may do so here:

Appendix A.2

Responses to CAPTEX survey by engineering students in PHY110W

Question	PHY110W Responses				
	Option				
	1	2	3	4	5
1	3	9	19	88	75
2	1	11	38	79	55
3	44	70	5	56	9
4	10	7	32	68	59
5	3	65	74	24	7
6	2	6	19	82	84
7	4	12	23	60	92
8	121	44	17	5	7
9	7	15	50	56	61
10	2	2	20	77	89
11	1	1	17	92	83
12	5	6	54	71	57
13	2	1	6	64	113
14	34	44	52	32	32
15	92	57	21	9	6
16	4	14	37	73	66
17	1	0	31	86	76
18	1	1	32	71	79
19	65	80	30	10	7
20	1	17	33	83	53
21	16	25	58	64	31
22	48	62	42	22	8
23	5	14	15	95	41
24	0	7	28	113	38
25	82	8	52	20	20

Appendix A.3

Responses to CAPTEX survey by science students in PHY123H

Question	PHY110W Responses				
	Option				
	1	2	3	4	5
1	5	7	15	27	44
2	1	14	31	44	34
3	28	51	13	13	7
4	7	6	12	42	56
5	18	27	38	30	10
6	1	3	7	40	75
7	32	24	32	25	9
8	83	23	13	4	2
9	9	18	27	31	39
10	1	1	19	33	71
11	1	5	5	40	74
12	8	4	25	35	51
13	3	4	9	38	70
14	28	17	36	24	20
15	65	28	13	12	3
16	4	1	32	42	17
17	2	5	21	41	55
18	1	3	21	49	49
19	35	31	26	16	12
20	6	5	16	28	68
21	23	19	29	25	27
22	24	29	26	28	16
23	1	8	35	47	27
24		4	22	53	44
25	61	28	16	12	4

Appendix A.4

Responses to CAPTEX survey by physics tutors

	Tutor's name							
Question	Mike	**Nawahl**	**Celia**	**Trevor**	**Mira**	**Bruce**	**Spencer**	**Average**
1	5	3	5	4	4	4	4	**4.1**
2	5	5	4	4	4	3	4	**4.1**
3	4	5	4	5	2	3	4	**3.8**
4	4	4	3	5	5	4	3	**4.0**
5	5	1	4	4	4	5	5	**4.0**
6	5	4	2	0	3	4	5	**4.0**
7	5	3	3	2	5	3	4	**3.5**
8	1	1	2	1	1	2	1	**1.2**
9	5	2	2	2	2	4	4	**3.0**
10	5	5	4	5	5	4	4	**4.5**
11	4	5	4	5	5	5	5	**4.7**
12	3	5	4	4	2	4	3	**3.5**
13	5	5	4	4	4	5	5	**4.5**
14	1	3	5	4	1	5	1	**2.8**
15	4		4	5	2	3	3	**3.5**
16	2	4	4	4	2	4	4	**3.4**
17	5	5	5	5	1	5	5	**4.4**
18	5	5	3	4	4	3	5	**4.1**
19	4	5	3	5	2	3	5	**3.8**
20	2	1	3	1	4	3	2	**2.2**
21	4	1	2	1	1	1	2	**1.7**
22	3	2	5	4	1	3	3	**3.0**
23	5	5	5	5	5	5	4	**4.8**
24	4	5	5	4	5	4	4	**4.4**
25	2	5	3	3	2	5	5	**3.5**

Appendix A.5

Responses to CAPTEX survey by physics lecturers

	Lecturuer's name									
Question	ABC	CAD	RDV	CMC	SMP	DGA	ZZV	DEF	DTB	**Avg**
1	5	3	5	4	4	4	5	5	4	**4.3**
2	4	5	5	5	5	4	5	5	5	**4.7**
3	4	5	5	4	3	4	4	4	4	**4.1**
4	4	3	5	4	5	3	4	4	4	**4**
5	2	2	5	3	4	4	5	5	4	**3.7**
6	4	5	5	5	4	2	5	4	3	**4.1**
7	2	3	3	2	3	2	2	3	4	**2.6**
8	1	2	3	1	1	2	2	2	1	**1.6**
9	4	3	1	2	2	5	3	5	3	**3.1**
10	3	2	3	4	4	4	2	3	4	**3.2**
11	3	5	5	5	5	5	5	4	4	**4.5**
12	1	5	3	5	4	4	2	3	4	**3.4**
13	3	5	5	4	5	4	3	4	4	**4.1**
14	1	1	1	2	2	2	3	1	2	**1.6**
15	2	5	5	4	4	3	1	1	4	**3.2**
16	4	3	5	2	5	4	4	3	4	**3.7**
17	3	5	5	5	5	4	5	5	4	**4.5**
18	3	2	3	5	5	4	4	1	3	**3.3**
19	4	3	3	3	3	4	4	3	4	**3.4**
20	3	3	3	5	3	2	2	3	2	**2.8**
21	1	1	3	2	1	3	4	5	2	**2.4**
22	4	4	3	3	3	4	4	2	4	**3.4**
23	4	5	5	5	4	4	5	4	4	**4.4**
24	4	5	5	5	4	3	3	4	5	**4.2**
25	3	3	3	4	4	4	4	3	1	**3.2**

Appendix B

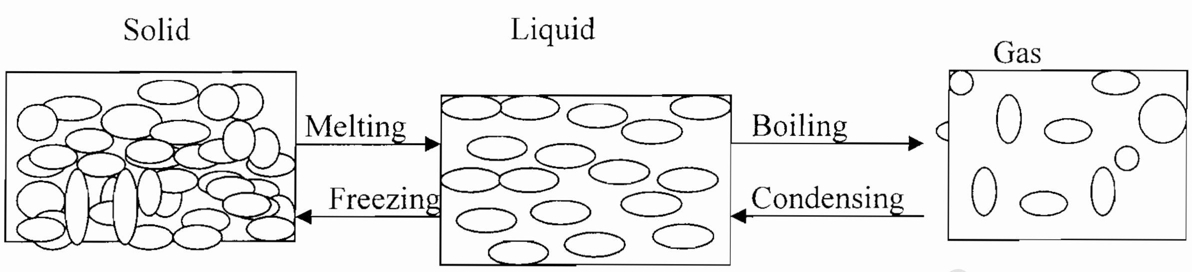
Record of video data collection

Date	Class	Exercise	No of Students	Time
28 03 03	P123H	Tutorial 6B	6	10 00 - 11 00
01 04 03	P123H	Worksheet 3	6	14 00 - 17 00
02 04 03	P110W	Tutorial 3	6	14 00 - 17 00
03 04 03	P123H	Tutorial 7A	6	10 00 - 11 00
03 04 03	P110W	Tutorial 4	6	14 00 - 17 00
04 04 03	P110W	Tutorial 4	6	08 00 - 09 00
04 04 03	P123H	Tutorial 7B	6	10 00 - 11 00
10 04 03	P123H	Tutorial 8A	3	10 00 - 11 00
11 04 03	P123H	Tutorial 8B	3	10 00 - 11 00
22 04 03	P121F	Tutorial 3	3	14 00 - 16 00
24 04 03	P123H	Tutorial 9A	3	10 00 -11 00
25 04 03	P110W	Worksheet 9	3	08 00 - 09 00
25 04 03	P123H	Tutorial 9B	3	10 00 - 11 00
08 05 03	P123H	Tutorial 11A	2	10 00 - 11 00
12 05 03	P110W	Tutorial 4	6	14 00 - 17 00
15 05 03	P123H	Tutorial 12A	3	10 00 - 11 00
16 05 03	Pi23H	Tutorial 12B	3	10 00 - 11 00
20 05 03	Pi23H	Worksheet 8	3	14 00 - 17 00
22 05 03	Pi23H	Tutorial 13A	3	10 00 - 11 00
15 07 03	P123H	Exercise 9	3	14 00 - 17 00
18 07 03	P123H	Tutorial 1	3	10 00 - 11 00
22 07 03	P122S	Tutorial 1	4	14 00 - 17 00
23 07 03	P110W	Tutorial 5	5	14 00 -17 00
24 07 03	P110W	Tutorial 5	3	14 00 - 17 00
25 07 03	P123H	Tutorial 2	3	10 00 - 11 00
29 07 03	P123H	Group task 1	3	10 00 - 11 00
30 07 03	P132S	Tutorial 1	3	14 00 - 17 00
01 08 03	P123H	Tutorial 3	3	10 00 - 11 00
06 08 03	P110W	Tutorial 6	3	14 00 - 17 00
07 08 03	Pi23H	Tutorial 4	3	10 00 - 11 00
12 08 03	P122S	Tutorial 2	3	14 00 - 17 00
15 08 03	P110W	Worksheet 18	2	08 00 - 09 00
15 08 03	P123H	Tutorial 5	3	10 00 - 11 00
19 08 03	P123H	Group task2	3	14 00 -17 00
12 09 03	P123H	Tutorial 8B	3	10 00 - 11 00
18 09 03	P110W	Tutorial 9	3	14 00 -17 00
19 09 03	P123H	Tutorial 9	3	10 00 -11 00
23 09 03	P122S	Tutorial 3	6	14 00 - 17 00
25 09 03	P110W	Tutorial 10	3	14 00 - 17 00
26 09 03	P123H	Tutorial 10	3	10 00 - 1100
30 09 03	P123H	Tutorial 4	3	14 00 - 17 00
03 10 03	P123H	Tutorial 11B	3	10 00 - 11 00
09 10 03	P110W	Tutorial 11B	3	14 00 - 17 00
10 10 03	P123H	Tutorial 12	3	10 00 - 11 00

Appendix C.1

Solution, Problem Analysis Sheet and Video Analysis Sheet for Case Study C

(a) Solution



- When water boils it changes state from a liquid to a gas. When it freezes it changes from a liquid to a solid.
- The temperature (which is kinetic energy of its molecules) at which these changes take place is dependent on the atmospheric pressure.
- Atmospheric pressure is more at sea level and less when one goes higher.
- One needs more energy (higher temperature) to boil water at sea level (Cape Town), because the pressure to overcome is higher than in Jo'burg.
- One needs lower temp to freeze the water in Jo' burg than Cape Town because the pressure to do so is less in Jo'burg

(b) Problem Analysis Sheet

University of Cape Town

Department of Physics

Problem Analysis Sheet

Analysis completed by: __Reuben__

Class: _PHY123 H_ **Tutorial no.**:_11__ **Problem no.**: _2_

A. The problem:

Water boils at 100 °C and freezes at 0 °C for sea level atmospheric pressure (Cape Town). At lower atmospheric pressure (e.g. Johannesburg, where altitude is 1.6 km) the same will boil and freeze at different temperatures. Explain this difference in detail.

B. List the main areas of physics content that are required to solve this problem:

Thermodynamics: Effect of temperature variation on fluids
Atmospheric pressure: variation with altitude

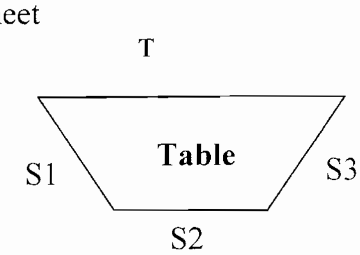
C. List the main problem solving procedures, skills and representations that are required for progress with this problem:

Conceptualising how atmospheric pressure; which depends on altitude, has an influence on the temperature at which a fluid changes state.

(c) Video Analysis Sheet

University of Cape Town
Department of Physics
Video Analysis Sheet

Seating arrangement:



Analysis completed by: Reuben

Date of tutorial: 03 /10 / 2003 **Time**: 10 00 – 11 00 **Class:** PHY123H
Tutorial no.: 11 **Question no.**: 2 **Venue**: Room L
Tutor's name: R **Group no.**: 42 **Call no.**: 2

(M)ale or (F)emale: **S1**: M **S2**: M **S3**: M
Predominant language used by group: English

(A) **Pre-tutor phase** (from 2 minutes prior to tutor being called):

A.1 Engagement of individuals (pre-tutor):

	S1	S2	S3
Talking:		√	√
Writing:			
"Engaged":	√	√	√

A.2 Sense of need:
_ _ _ Check progress of group ___ Group needs information
_√ _ Group stuck on problem Other _ _ _ _ _ _ _ _ _

A.3 Give particular details about why the tutor is called, with reference to "problem information" sheet:

Effects of atmospheric pressure change on boiling and freezing

A.4 Consensus to call tutor: S1:_ _ _ S2: _ _ _ S3:_ √_
A.5 who calls the tutor S1:_ _ _ S2:_ _ _ S3:_ √_

(B) Tutor interaction:

B.1 Time that tutor spends with group: _ _-_ minutes
B.2 Indicate position of tutor (T) on diagram above.

B.3 Style of initial contact:

	S1	S2	S3	T
Who speaks first?			√	
Who asks first question?				√
Who takes initial control?				

B.4 Initial tutoring style: ___"Telling" __√_ "Questioning"

B.5 Has the tutor discerned the exact need of the group, with respect to A.3 above? _ √__ yes _ _ _ no

B.6
Distribution of questioning by tutor:

S1	S2	S3
	√	

B.7 Type of questioning:
_ _ To find where the difficulty is
_√_ Socratic (to draw out understanding)

B.8
Distribution of telling by tutor:

S1	S2	S3
	√	

B.9 Type of telling: _ _ Procedural _√_ Content

B.10 Does B.7 and B.9 relate directly to the need of the students with respect to A.3 above? __√__ yes _ _ _ No

B.11
Engagement of individuals with tutor:

	S1	S2	S3
Talking:	√	√	√
Writing:			
"Engaged":	√	√	√

B.12
Before leaving, the tutor checks understanding of : *None*

S1	S2	S3

(C) Post-tutor phase (until 2 minutes after tutor leaves):

C.1
Engagement of individuals (post-tutor):

	S1	S2	S3
Talking:	√	√	√
Writing:			
"Engaged":	√	√	√

C.2 Is progress made with respect to the reason why the group called the tutor (refer to A.3)? __√__ yes ___ no

C.3
Students' need fulfilled (with respect to A.3) ?

S1	S2	S3

C.4 Tutor called for same difficulty:
_ _ _ Same tutor _ _ _ Different tutor
_ _ _ Immediately _ __Later: _ _ _ minutes

Comments:
- This tutor used an almost balanced approach of questioning and telling
- This conceptual question encouraged active participation among all members of the group
- The tutor left without checking whether all members of the group understand.

Appendix C.2

Solution, Problem Analysis Sheet and Video Analysis Sheet for Case Study D

(a) Solution

For velocity along the x and y direction:

$$V(t) = vo + at;$$
$$Vox = vo \cos oi$$
$$Voy = vo \sin 0 j$$
$$Vx(t) = Vox + axt$$
$$= 50 \cos 53 + 0$$
$$Vy(t) = voy + ayt$$
$$= 50 \sin 53 (j) + 10(-j)t$$

For position along the x and y direction:

$$x(t) = x_o + v_o xt + 1/2at^2$$
$$y(t) = y_0 + voyt + 1/2ayt^2$$

(b) Problem Analysis Sheet

University of Cape Town

Department of Physics

Problem Analysis Sheet

Analysis completed by: _ Reuben _

Class: _PHY123 H _ **Tutorial no.**: _1 _ **Problem no.**:_ 2 _

A. The problem:

A ball is projected from the origin with initial velocity Vo, as shown at the right .The initial speed of the ball is 50 m/s . Assume that g = 10 m/s^2.
Complete the table bellow indicating the position components at one second time- intervals beginning at time zero when the ball leaves the ground.

Time (s)	X velocity (m/s)	X position (m)	Y Velocity (m/s)	Y position (m)
0		0		0
1				
2				
3				
4				
5				
6				
7				

B. List the main areas of physics content that are required to solve this problem:

Projectile motion; there is acceleration (downward) only in the vertical direction; acceleration in the horizontal direction is always zero; the horizontal component of velocity is the same at all times.

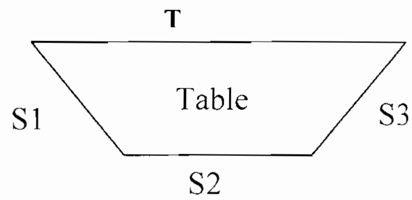
C. List the main problem solving procedures, skills and representations that are required for progress with this problem:

Draw the trajectory of the projectile
Identify the two equation of position and velocity as they apply to projectile motion
Substitute values of t in the simplified equations in the same way.

(c) Video Analysis Sheet

University of Cape Town
Department of Physics
Video Analysis Sheet

Seating arrangement:



Analysis completed by: Reuben

Date of tutorial: 29 / 07 / 2003 **Time:** 14 00 - 1700 **Class:** PHY123 H
Tutorial no.: Group task 1 **Question no.:** 2e1 **Venue:** Room L
Tutor's name: N **Group no.:** 26 **Call no.:** 2

(M)ale or (F)emale: **S1:** F **S2:** M **S3:** M
Predominant language used by group: English

A) Pre-tutor phase (from 2 minutes prior to tutor being called):

A.1 Engagement of individuals (pre-tutor):

	S1	S2	S3
Talking:		√	√
Writing:			
"Engaged":	√	√	√

A.2 Sense of need: _ _ _ Check progress of group _ _ _ Group needs information
_ _ _ Group stuck on problem Other: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

A.3 Give particular details about why the tutor is called, with reference to "problem information" sheet:
Group needs to know how calculate velocity and position of a projectile at a particular time

A.4 Consensus to call tutor: S1: _ _ _ S2: _ √ _ S3: _ _ _
A.5 Who calls the tutor?: S1: _ _ _ S2: _ √ _ S3: _ _ _

B) Tutor interaction phase:

B.1 Time that tutor spends with group: _ _ _ minutes
B.2 Indicate position of tutor (T) on diagram above.

B.3 Style of initial contact:

	S1	S2	S3	T
Who speaks first?		√		
Who asks first question?				√
Who takes initial control?			√	

B.4 Initial tutoring style: _ _ _ "Telling" _ √ _ "Questioning"

B.5 Has the tutor discerned the exact need of the group, with respect to A.3 above? _√_ Yes _ _ _No

B.6
Distribution of questioning by tutor:

S1	S2	S3
	√	√

B.7 Type of questioning:
_ _ _ To find where the difficulty is
_√_ Socratic (to draw out understanding)

B.8
Distribution of telling by tutor:

S1	S2	S3
	√	√

B.9 Type of telling: _ _ _ Procedural __√__ Content

B.10 Does B.7 and B.9 relate directly to the need of the students with respect to A.3 above? __√__ Yes _ _ _ No

B.11
Engagement of individuals with tutor:

	S1	S2	S3
Talking:		√	√
Writing:			
"Engaged":		√	√

B.12
Before leaving, the tutor checks understanding of : None

S1	S2	S3

(C) Post-tutor phase (until 2 minutes after tutor leaves):

C.1
Engagement of individuals (post-tutor):

	S1	S2	S3
Talking:		√	√
Writing:		√	
"Engaged":		√	√

C.2 Is progress made with respect to the reason why the group called the tutor (refer to A.3)? _√_ yes _ _ _ no

C.3
Students' need fulfilled (with respect to A.3):

S1	S2	S3
	√	√

C.4 Tutor called for same difficulty:
_ _ _ same tutor _ _ _ Different tutor
_ _ _ immediately _ _ _ later: _ _ _ minutes

Comments:

- Tutor completely ignores **S1**
- Tutor leaves without checking whether all students in the group understand

Appendix C.3

Solution, Problem Analysis Sheet and Video Analysis Sheet for Case Study E

(a) Solution

$$J = \int f(t)\, dt = \square P$$

$$= \int_0^2 [(1-t)\bar{i} + t2\bar{j} - \bar{k}]dt$$

$$= [(t - t2/2)i + t3/3j - tk]$$

$$= 8/3j - 2k = P = mv$$

$$\therefore \Delta v = vf - vi = \Delta p/m = (8/3j - 2k)/4 - i$$

(b) Problem Analysis Sheet

University of Cape Town

Department of Physics

Problem Analysis Sheet

Analysis completed by: _ Reuben_

Class: _ PHY123 H_ **Tutorial no.**:_12_ **Problem no.**: _2_

A. The problem:

Impulse J is defined as the integral of force with respect to time and is also equal to change in momentum, as indicated below. The integral is evaluated over the time that the force is applied

$$\mathbf{J} = \int \mathbf{f}\,(\mathbf{t})\mathbf{dt} = \Delta\mathbf{P}$$

Find the impulse of the force $F = (1- t)i + t^2 j - k$ between $t = 0$ and $t = 2$ seconds. What is the final velocity of a 4 kg object if this impulse is applied to it while travelling at 1 ms^{-1} in the i direction.

B. List the main areas of physics content that are required to solve this problem:

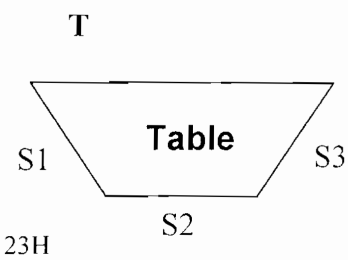
Momentum: a product of mass and change in velocity $P = m\Delta v$
Impulse: the change in momentum

C. List the main problem solving procedures, skills and representations that are required for progress with this problem:

Integration:
Solve for v_f : $\Delta v = v_f - v_i = \Delta P/m$

(c) Video Analysis Sheet

University of Cape Town
Department of Physics
Video Analysis Sheet



Seating arrangement:

Analysis completed by: Reuben

Date of tutorial: 16 / 05 / 2003 **Time**: 10 00 – 11 00 **Class**: PHY123H
Tutorial no.: 2 **Question no**.: 2 **Venue**: Room L
Tutor's name: C **Group no**.: 17 **Call no**.: 2

(M)ale or (F)emale: **S1**: M **S2**: F **S3**: F
Predominant language used by group: English

(A) Pre-tutor phase (from 2 minutes prior to tutor being called):

A.1 Engagement of individuals (pre-tutor):

	S1	S2	S3
Talking:	√		√
Writing:			
"Engaged":	√	√	√

A.2 Sense of need:
_ _ _ Check progress of group _ _ _ Group needs information
_√_ Group stuck on problem Other:_ _ _ _ _ _ _ _ _ _ _ _ _ _

A.3 Give particular details about why the tutor is called, with reference to "problem information" sheet:
Group needs to know how to find velocity after doing the intergaration

A.4 Consensus to call tutor: S1:_√_ S2:_ _ _√_ S3:_ _ _
A.5 Who calls the tutor?: S1:_ _ _ S2:_√_ S3:_ _ _

(B) Tutor interaction:

B.1 Time that tutor spends with group: _ _ _ minutes
B.2 Indicate position of tutor (T) on diagram above.

B.3 Style of initial contact:

	S1	S2	S3	T
Who speaks first?		√		
Who asks first question?				√
Who takes initial control?				√

B.4 Initial tutoring style: _ _ _"Telling" _√_ "Questioning"

B.5 Has the tutor discerned the exact need of the group, with respect to A.3 above? _√_ Yes _ _ _ No

B.6
Distribution of questioning by tutor:

S1	S2	S3
	√	

B.7 Type of questioning:
_ _ _ To find where the difficulty is
_ √ _ Socratic (to draw out understanding)

B.8
Distribution of telling by tutor:

S1	S2	S3
√	√	√

B.9 Type of telling: _√_ Procedural _ _ _ Content

B.10 Does B.7 and B.9 relate directly to the need of the students with respect to A.3 above? _√_ Yes _ _ _No

B.11
Engagement of individuals with tutor:

	S1	S2	S3
Talking:	√	√	√
Writing:			
"Engaged":	√	√	√

B.12
Before leaving, the tutor checks understanding of : None

S1	S2	S3

(C) Post-tutor phase (until 2 minutes after tutor leaves):

C.1
Engagement of individuals (post-tutor):

	S1	S2	S3
Talking:	√	√	√
Writing:	√	√	√
"Engaged":	√	√	√

C.2 Is progress made with respect to the reason why the group called the tutor (refer to A.3)? _√__ Yes _ _ _No

C.3
Students' need fulfilled (with respect to A.3):

S1	S2	S3
	√	√

C.4 Tutor called for same difficulty:
_ _ _Same tutor _ _ _ Different tutor
_ _ _ Immediately _ _ _ later: _ _ _ minutes

Comments:

- Tutor used an approach balanced with questions and information (almost Socratic) to draw out understanding
- Tutor left without checking how the students will use the new information she gave them to progress.

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